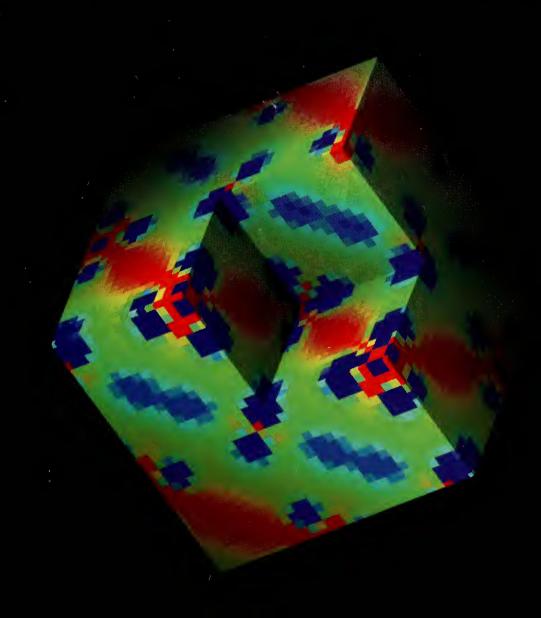


CARNEGIE INSTITUTION OF WASHINGTON

Extending the Frontiers of Science YEAR BOOK 97198

1997-1998



On the cover: Above: The image shows a stage of mitosis in the newt. (see p. 6, Courtesy R. V. Skibbens, Carnegie Department of Embryology, and E. D. Salmon, University of North Carolina.)

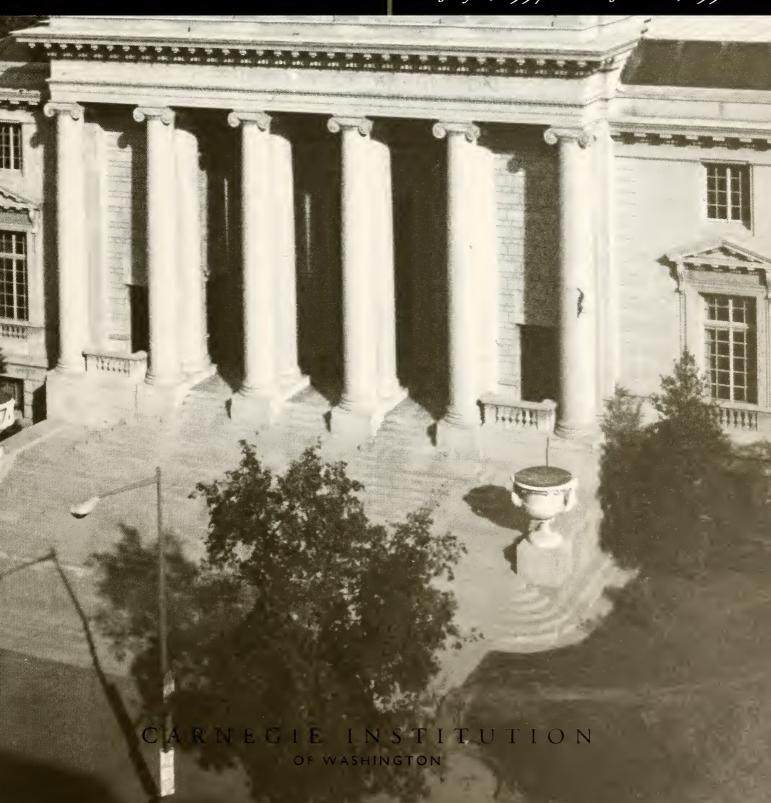
Below: The lower image is a computer computation of FeO at high pressures. FeO is an important constituent of the Earth's mantle. The red regions indicate a strong bonding between iron atoms. The bonding leads to a shearing, or distortion, of the crystal structure which becomes more pronounced with increasing pressure. (Courtesy Ronald Cohen, Carnegie Geophysical Laboratory and Donald Isaak, UCLA.)



Year Book 97/98

THE PRESIDENT'S REPORT

July 1, 1997 — June 30, 1998



ABOUT CARNEGIE

...TO ENCOURAGE, IN THE BROADEST AND MOST LIBERAL MANNER, INVESTIGATION, RESEARCH, AND DISCOVERY, AND THE APPLICATION OF KNOWLEDGE TO THE IMPROVEMENT OF MANKIND ...

The Carnegie Institution of Washington was incorporated with these words in 1902 by its founder, Andrew Carnegie. Since then, the institution has remained true to its mission. At five research departments across the country, the scientific staff and a constantly changing roster of students, postdoctoral fellows, and visiting investigators tackle fundamental questions on the frontiers of biology, earth sciences, and astronomy.

Department of Embryology

115 West University Parkway Baltimore, MD 21210-3301 410.467.1414

Department of Plant Biology

260 Panama St. Stanford, CA 94305-4101 650.325.1521

Geophysical Laboratory

5251 Broad Branch Rd., N.W. Washington, DC 20015-1305 202.686.2410

Department of Terrestrial Magnetism

5241 Broad Branch Rd., N.W. Washington, DC 20015-1305 202.686.4370

The Carnegie Observatories

813 Santa Barbara St. Pasadena, CA 91101-1292 626.577.1122

Las Campanas Observatory

Casilla 601 La Serena, Chile

Office of Administration

1530 P St., N.W. Washington, DC 20005 202.387.6400 http://www.ciw.edu

CONTENTS

The President's Commentary	7
Losses, Gains, Honors	15
Contributions, Grants, and Private Gifts	19
First Light and CASE	21
Department of Plant Biology	25
Department of Embryology	37
The Observatories	47
Department of Terrestrial Magnetism	59
Geophysical Laboratory	75
Extradepartmental and Administrative	87
Financial Statements	89
Index of Names	101

Former Presidents & Trustees

PRESIDENTS

Daniel Coit Gilman, 1902-1904
Robert S. Woodward, 1904-1920
John C. Merriam, 1921-1938
Vannevar Bush, 1939-1955
Caryl P. Haskins, 1956-1971
Philip H. Abelson, 1971-1978
James D. Ebert, 1978-1987
Edward E. David, Jr. (Acting President, 1987-1988)

TRUSTEES

Alexander Agassiz, 1904-1905 Robert O. Anderson, 1976-1983 Lord Ashby of Brandon, 1967-1974 J. Paul Austin, 1976-1978 George G. Baldwin, 1925-1927 Thomas Barbour, 1934-1946 James F. Bell, 1935-1961 John S. Billings, 1902-1913 Robert Woods Bliss, 1936-1962 Amory H. Bradford, 1959-1972 Lindsay Bradford, 1940-1958 Omar N. Bradley, 1948-1969 Lewis M. Branscomb, 1973-1990 Robert S. Brookings, 1910-1929 James E. Burke, 1989-1993 Vannevar Bush, 1958-1971 John L. Cadwalader, 1903-1914 William W. Campbell, 1929-1938 John J. Carty, 1916-1932 Whitefoord R. Cole, 1925-1934 John T. Connor, 1975-1980 Frederic A. Delano, 1927-1949 Cleveland H. Dodge, 1903-1923 William E. Dodge, 1902-1903 Gerald M. Edelman, 1980-1987 Charles P. Fenner, 1914-1924 Michael Ference, Jr., 1968-1980 Homer L. Ferguson, 1927-1952 Simon Flexner, 1910-1914 W. Cameron Forbes, 1920-1955 James Forrestal, 1948-1949 William N. Frew, 1902-1915 Lyman J. Gage, 1902-1912 Walter S. Gifford, 1931-1966

Carl J. Gilbert, 1962-1983 Cass Gilbert, 1924-1934 Frederick H. Gillett, 1924-1935 Daniel C. Gilman, 1902-1908 Hanna H. Gray, 1974-1978 Crawford H. Greenewalt, 1952-1984 William C. Greenough, 1975-1989 Patrick E. Haggerty, 1974-1975 John Hay, 1902-1905 Barklie McKee Henry, 1949-1966 Myron T. Herrick, 1915-1929 Abram S. Hewitt, 1902-1903 Henry L. Higginson, 1902-1919 Ethan A. Hitchcock, 1902-1909 Henry Hitchcock, 1902 Herbert Hoover, 1920-1949 William Wirt Howe, 1903-1909 Charles L. Hutchinson, 1902-1904 Walter A. Jessup, 1938-1944 Frank B. Jewett, 1933-1949 George F. Jewett, Jr., 1983-1987 Antonia Ax:son Johnson, 1980-1984 William F. Kieschnick, 1985-1991 Samuel P. Langley, 1904-1906 Kenneth G. Langone, 1988-1994 Ernest O. Lawrence, 1944-1958 Charles A. Lindbergh, 1934-1939, William Lindsay, 1902-1909 Henry Cabot Lodge, 1914-1924 Alfred L. Loomis, 1934-1973 Robert A. Lovett, 1948-1971 Seth Low, 1902-1916 John D. Macomber, 1981-1990 Wayne MacVeagh, 1902-1907 William McChesney Martin, 1967-1983 Keith S. McHugh, 1950-1974 Andrew W. Mellon, 1924-1937 John C. Merriam, 1921-1938 J. Irwin Miller, 1988-1991 Margaret Carnegie Miller, 1955-1967 Roswell Miller, 1933-1955 Darius O. Mills, 1902-1909 S. Weir Mitchell, 1902-1914 Andrew J. Montague, 1907-1935 Henry S. Morgan, 1936-1978 William W. Morrow, 1902-1929 Seeley G. Mudd, 1940-1968

Franklin D. Murphy, 1978-1985

William I. Myers, 1948-1976 Garrison Norton, 1960-1974 Paul F. Oreffice, 1988-1993 William Church Osborn, 1927-1934 Walter H. Page, 1971-1979 James Parmelee, 1917-1931 William Barclay Parsons, 1907-1932 Stewart Paton, 1916-1942 Robert N. Pennoyer, 1968-1989 George W. Pepper, 1914-1919 John J. Pershing, 1930-1943 Henning W. Prentis, Jr., 1942-1959 Henry S. Pritchett, 1906-1936 Gordon S. Rentschler, 1946-1948 Sally K. Ride, 1989-1994 David Rockefeller, 1952-1956 Elihu Root, 1902-1937 Elihu Root, Jr., 1937-1967 Julius Rosenwald, 1929-1931 William M. Roth, 1968-1979 William W. Rubey, 1962-1974 Martin A. Ryerson, 1908-1928 Howard A. Schneiderman, 1988-1990 Henry R. Shepley, 1937-1962 Theobald Smith, 1914-1934 John C. Spooner, 1902-1907 William Benson Storey, 1924-1939 Richard P. Strong, 1934-1948 Charles P. Taft, 1936-1975 William H. Taft, 1906-1915 William S. Thayer, 1929-1932 Juan T. Trippe, 1944-1981 lames W. Wadsworth, 1932-1952 Charles D. Walcott, 1902-1927 Frederic C. Walcott, 1931-1948 Henry P. Walcott, 1910-1924 Lewis H. Weed, 1935-1952 William H. Welch, 1906-1934 Gunnar Wessman, 1984-1987 Andrew D. White, 1902-1916 Edward D. White, 1902-1903 Henry White, 1913-1927 James N. White, 1956-1979 George W. Wickersham, 1909-1936 Robert E. Wilson, 1953-1964 Robert S. Woodward, 1905-1924 Carroll D. Wright, 1902-1908

Trustees

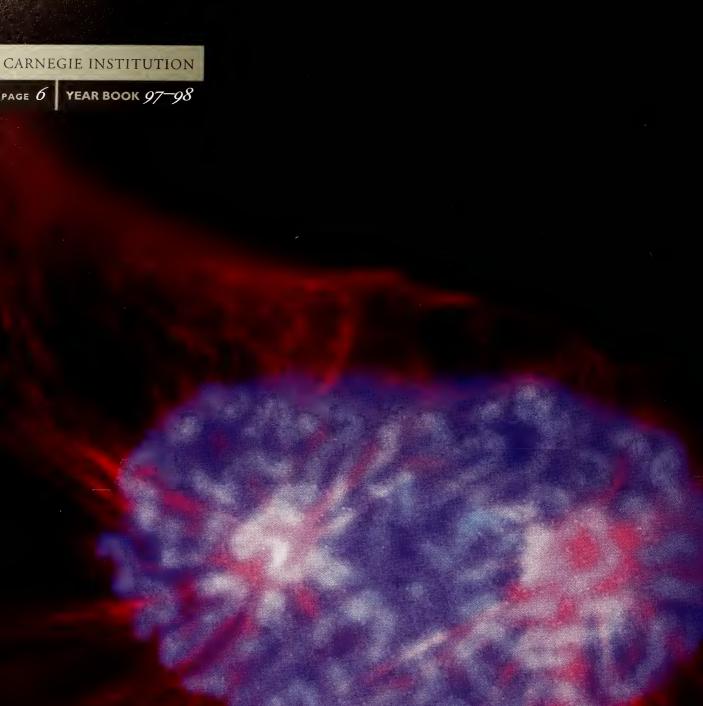
Thomas N. Urban, *Chairman*William I. M. Turner, Jr., *Vice-Chairman*William T. Golden, *Secretary*

Philip H. Abelson Euan Baird William T. Coleman, Jr. John F. Crawford Edward E. David, Jr., Emeritus John Diebold James D. Ebert W. Gary Ernst Sandra M. Faber Bruce W. Ferguson Michael E. Gellert Robert G. Goelet David Greenewalt Caryl P. Haskins, *Emeritus* William R. Hearst III Richard E. Heckert, Emeritus William R. Hewlett, Emeritus Kazuo Inamori Suzanne Nora Johnson Gerald D. Laubach John D. Macomber Burton J. McMurtry Richard A. Meserve Richard S. Perkins, Emeritus Frank Press William J. Rutter Robert C. Seamans, Jr., Emeritus Frank Stanton, Emeritus Christopher Stone David F. Swensen Charles H. Townes, Emeritus Sidney J. Weinberg, Jr.

> President Maxine Frank Singer

> > Directors

Augustus Oemler, Jr. The Observatories
Charles T. Prewitt, Geophysical Laboratory
Sean C. Solomon, Department of Terrestrial Magnetism
Christopher Somerville, Department of Plant Biology
Allan C. Spradling, Department of Embryology
John J. Lively, Administration and Finance
Susanne Garvey, External Affairs



A stage of mitosis in the newt. The cells were fixed and then stained with DAPI to visualize the DNA; an antibody directed against tubulin allows one to see the microtubules and spindle apparatus. (Courtesy R. V. Skibbens, Carnegie Department of Embryology, and E. D. Salmon, University of North Carolina.)

THE EYE IS NEVER SATISFIED WITH SEEING; ENDLESS ARE THE DESIRES OF THE HEART.

GATES OF REPENTANCE. THE NEW UNION PRAYERBOOK FOR THE DAYS OF AWE.

Central Conference of American Rabbis. New York, 1978.

L ast spring I attended a meeting about that perennial question, the state of university education. Scholars concerned with the humanities spoke about their own undergraduate experiences with classical philosophers and authors. Many decades later, they could still reach easily into their considerable memories and find there pertinent quotations and fresh ideas. Their university educations are the living foundations of their current efforts. My own educational memories, as least as many decades old as theirs, are somewhat different. Aside from several fundamental matters in the physical and biological sciences, few specifics that I learned in college or university are relevant to today's science and a lot have since been proven wrong. Scientists must continually revise the scientific ideas stored in their heads. I pointed out that while they had been trying hard for as much as half a century to remember what they had learned as students, I had been working to forget. They were astounded and certain I must be wrong, until another scientist in the room concurred with me.

After the meeting I wondered if I had exaggerated. As I was also thinking then about my tenth anniversary as president of the Carnegie Institution, the two questions merged in a consideration of the past decade. Marking the changes in research directions and methods is an essential window on the health of a scientific institution.

To begin to assess the changes in Carnegie science over the last decade, I asked each staff member to send me a copy of her or his most significant paper of the past year. Several general impressions emerged from reading them. For one, Carnegie scientists are collaborating more, both with their colleagues within the institution and with scientists

from around the world. For another, their research has come to depend increasingly on centralized, often government-sponsored national and international facilities, such as synchrotrons, space telescopes, satellites, computer networks, and data banks. A good example is DTM's Selwyn Sacks' ongoing investigation of the rate of convergence of the Nazca and South American tectonic plates along the western coast of South America. Collaborating with Sacks are scientists from Peru and several U.S. institutions. The geodetic data they used were obtained from a national system of global positioning satellites.

Among all the changes that impressed me, three have particularly profound and interdependent effects on the science carried out across the Carnegie departments. All three reflect the capacities of computers. One stems from the implications of large data banks. Another concerns the basic scientific tool of model building. And the third is the revolution in the ability to generate images. It is commonplace to note that computers are altering the foundations of human culture and society. Less widely appreciated are the influences that novel science, generated with computers, will have on those altered foundations.

THE NEW COLLECTIONS

Natural history museums all over the world store a wide range of preserved specimens, bones, and rocks. Scholarship still focuses on these often haphazard or eclectic collections, and continues to yield essential information on the evolution of the biological and physical Earth. In its early years, the Carnegie Institution started its own collections.

The Department of Embryology's unique human embryo collection is now carefully housed at the National Museum of Health and Medicine of the Armed Forces Institute for Pathology in Washington D.C., where it is available to scholars. The large collection of photographic plates from the Mount Wilson Observatory is accessible at the Observatories' headquarters in Pasadena. These plates remain useful by providing, among other data, benchmarks to chart changes in the sky.

The newest scientific collections are not concrete entities. Their sizes are not limited by available physical space or curatorial resources. They consist of vast amounts of information that reside in computer data bases, not museum shelves. They can be

Astronomers no longer use photographic plates to study the sky, but rely instead on computers that can readily access data stored in large memory banks. Above, Carnegie astronomer Edwin Hubble (1889-1953) examines one of the plates from the Mount Wilson collection. Below, the Observatories' Patrick McCarthy examines his data

using a computer.

accessed from anywhere on Earth, and even from space. Some of these data bases are constructed from painstakingly gathered and recorded information. Others represent the direct input of data acquired by instruments. Thus, computers not only permit the storage of large bodies of data: they spur the making of collections.

Examples abound. In genetics, the sequencing of individual genes necessitated the development of data base storage techniques. This in turn stimulated the development of tools to access and manipulate the data. Large-scale projects to sequence whole genomes foster improved methods for computer-dependent data acquisition, recording, and retrieval. In astronomy, modern instrumentation often provides more data than is of interest to the astronomer who collects it. Similarly, vast amounts of data are collected by satellites and space probes and by the increasingly sophisticated and sensitive instruments used for experimental earth science. Placed in data bases, the information tangential to a particular project is thus stored for future research.

Collecting vast amounts of data is one thing. Being able to use the information in the service of science is another. Today, the genome data banks can be queried about various aspects of gene and protein structure and used to search for similarities between genes within an organism or among different organisms, or to identify single active genes. In a series of experiments at the Department of Plant Biology, Krishna Niyogi, Olle Björkman, and Arthur Grossman used such tools to advance understanding of the way plants protect themselves from excess light. Winslow Briggs applied the tools to a problem that has long intrigued him: the mechanism by which plants respond to blue light. Don Brown and Alejandro Sánchez Alvarado at the Department of Embryology depended on data banks to identify genes that are turned on or off in response to major physiological upheavals: metamorphosis in toads and regeneration in planaria, respectively. And the data banks they used weren't restricted to toad and planaria genes. Because of the remarkable similarity among genes in different organisms, planaria and toad genes can often be characterized by referring to data banks for fly, human, or yeast genes.

In all of these studies, computers played a secondary role. The questions were posed by the scientists. Answers were obtained by a lot of hard, experimental work. The computers only assisted. And the investigations necessarily proceeded one gene or at most a few genes at a time.

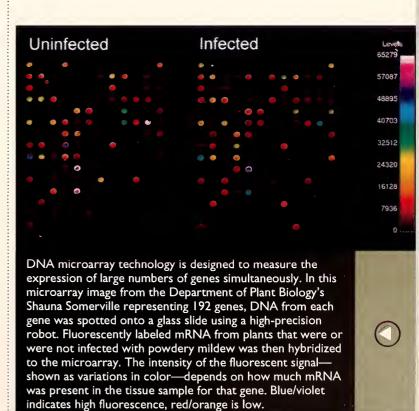
Scientists now recognize that unexpected questions are likely to emerge from experimentation with the data banks themselves, if only sufficiently intelligent and innovative tools can be developed to manipulate them. Christopher Somerville and Shauna Somerville, among others, have been thinking about this issue in relation to biology (see this Year Book, pp. 27). One challenging task is to design the data bases so that they are maximally useful in the future. This itself may produce novel science because it requires trying to imagine what new questions may emerge. Another task is to develop techniques that encompass more than one or a few genes at a time. Shauna Somerville, for example, is working on methods that will, in single experiments, obtain and store data on entire networks of plant genes that respond to particular environmental stimuli, both internal and external, in individual cell types. The next task, the province of the new field of bioinformatics, is to develop techniques that will synthesize the many simultaneous discrete responses into a coherent and comprehensive understanding. Such tools will also be useful to developmental biologists like Brown and Sánchez Alvarado. The capacity of computers to handle simultaneously a large number of variables will undoubtedly permit new insights on a variety of complex questions.

BUILDING MODELS

One approach to mining the depths of the data banks for the solution of complex problems is the time-honored scientific practice of making models. Models are plausible explanations for poorly understood phenomena. Computers have enhanced the range and detail of model construction over earlier paper-and-pencil techniques. Computers can also test models against relevant banked data. Some models will be discarded. Others, perhaps only one,

will fit the data and can be adopted, at least tentatively, as an explanation. A good example of this approach is Sean Solomon's work on the ridged lava plains observed on the surface of Venus by the Magellan mission. Solomon and his collaborators used computers to construct and test models for ridge formation. The analysis suggests that the ridges arose in response to great fluctuations in the atmospheric and surface temperatures of the planet, not through purely tectonic processes.

At the Department of Plant Biology, Joe Berry, Chris Field, and collaborators used computer models to analyze the effect of a doubling of atmospheric carbon dioxide on large ecosystems. They coupled a general model for atmospheric circulation with a terrestrial biosphere model that they derived using extensive banked experimental data on the nutritional status of the plant species, the exchanges of heat and water between plants and atmosphere, and various environmental factors, including temperature and water levels. The combined models predict that at some latitudes, temperature will rise more than one degree over and above that predicted by the greenhouse effect of increased atmospheric carbon dioxide. The Berry and Field results will need to be refined with additional data. But without access to satellite-acquired data on the



type, density, and color of vegetation, and the computational power of modern computers, such models could not be tested or refined.

Similarly, powerful computers enable DTM's Alan Boss and George Wetherill to model and test theories about the origin of solar systems, our own and those around other stars. And François Schweizer points out that computers are the experimental tools with which models for evolution of galaxies and complex galactic interactions can be simulated, providing blueprints for the data needed to test the models.

NEW EYES

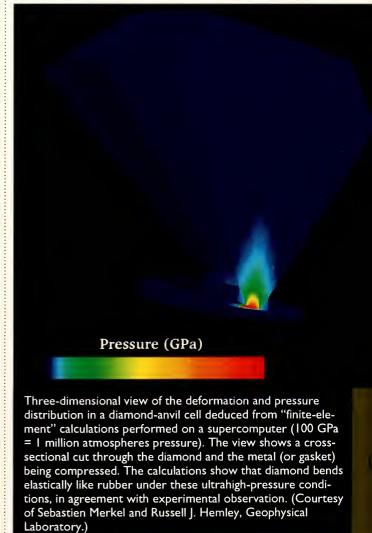
The abundance and clarity of images in current scientific papers is remarkable. This revolution in data presentation hails from the ability of computers to convert digitized information into images—on paper or the internet. Many of these visual experiences were unimaginable even a few years ago. In September of this year, for example, I watched over the internet from my home in Washington, D.C., as the glass for the Magellan II

Equatorial view of a protoplanetary disk, simulated by DTM's Alan Boss using a program that calculates the three-dimensional flow of gas and dust. This disk is undergoing a phase of gravitational instability leading to spiral arm formation. A solar-mass protostar lies unseen at the disk's center.

mirror melted inside the spinning oven at the University of Arizona. But even more extraordinary is that we now routinely see what was previously invisible. Computers have given us eyes that evolution, for all its elegance and competence, did not. There is even a site on the web that displays images as seen by a honeybee!

Our computer-given eyes accomplish three especially wonderful feats. They see images at wavelengths outside of what we call the visible region of the electromagnetic spectrum. They see hidden things. They see images constructed out of data that have little or nothing to do with light at any wavelength.

Seeing invisible light. The visible region of the electromagnetic spectrum—the region our eyes detect—includes wavelengths for the familiar red, orange, yellow, green, blue, and violet colors and also accounts for the white we see when light at all these wavelengths arrives together on our retinas. Much larger regions of the spectrum are invisible

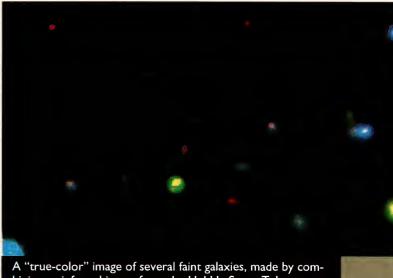


to human eyes, including, at wavelengths longer than that of red light, infrared (heat) and radiowaves, and, at wavelengths shorter than that of visible light, ultraviolet, gamma, and x radiation.

Carnegie astronomers are making extensive use of the invisible parts of the electromagnetic spectrum. Infrared and radiowaves are now collected by ground- and space-based telescopes. Space telescopes above Earth's atmosphere record x-ray and ultraviolet wavelengths. By scanning across a galaxy with appropriate detectors, light of particular wavelengths can be sensed and the spectra beamed to Earth-based computers. The computers then convert the spectra into graphs and falsecolor images, with the colors representing light intensities at invisible wavelengths. The pictures show the distribution of material and energy. For example, they illustrate the diffuse gas that exists around stars, nebulae, and galaxies, and thus provide a more complete picture of the stuff that is out there. Without such computer-generated images, we would have no way to see light outside of the visible region of the spectrum, even if we journeyed into space ourselves. As Gus Oemler points out in his essay (see pp. 47), we are no longer limited to seeing just starlight.

The last upgrade of the Hubble telescope provided a camera capable of taking images from the near-infrared part of the spectrum. This is important because it allows astronomers to image light emitted from very distant, ancient objects which, because of the Doppler effect, is shifted into the infrared by the time it reaches Earth. Using the infrared camera, Ray Weymann, Pat McCarthy, and their postdoctoral colleagues at the Observatories found that the number of galaxies per unit area of the sky gets bigger as galaxies become fainter and smaller. This makes sense if, as believed, closer (and newer) galaxies formed from mergers of gravitationally interacting smaller (and older) ones.

Seeing hidden things. The invention of microscopes in the 17th century led to the discovery of cells and chromosomes. Since then, advances in microscopy have continued to transform biology. The electron microscope, for example, magnifies objects a thousand times more than traditional light microscopes, which expand images only up to about sev-



A "true-color" image of several faint galaxies, made by combining an infrared image from the Hubble Space Telescope with blue and green images from the Keck 10-m telescope in Hawaii. The red galaxies are seen only or primarily in the near-IR images, and are most likely a cluster of massive galaxies at large redshifts. The blue galaxies are closer to us. (Courtesy of Lin Yan, Lisa Storrie-Lombardi, Ray Weymann, and Patrick McCarthy, all of the Observatories.)

eral-hundred fold. Scanning electron microscopy gives three-dimensional images. Video cameras attached to microscopes yield dynamic rather than static images. Videos are now even part of published papers; in these instances, the reader is guided to web site addresses for viewing.

Clever, insightful interpretation of cellular structures seen in microscopes gives important but inconclusive clues as to function. In the past decade, however, ways have been found to couple the structural information seen in the microscope with definitive functional data obtained from biochemical experiments. The key is to associate the presence of particular proteins with specific, intracellular structures. The dependence of the structure on the protein's function can then be experimentally confirmed by inhibiting or destroying the gene that specifies the protein.

Two different techniques mark the presence of a particular gene product or protein in microscopic images. In one, the sample is treated with an antibody that binds to that protein and no other; the antibody itself is chemically marked with a fluorescent tag. In the second technique, the protein's gene is first reconstructed to include the genetic code for a naturally fluorescent protein; whatever cell types naturally express the gene will then fluoresce. Especially productive application of these methods

derives from their use in conjunction with what is called a confocal microscope. Confocal microscopes use laser light of particular wavelengths (chosen to match the fluorescent tag). The light is focused on a single plane of the sample and scanned across that plane, making individual images at various points. The digitized images are computer-synthesized into a picture across the plane.

The extraordinary insights afforded by confocal microscopy are illustrated by the work of Joe Gall and his colleagues at the Department of Embryology. They have revisited what were, before their recent experiments, enigmatic structures within cell nuclei called coiled bodies. These bodies were described as early as 1913 and first caught Gall's attention in 1954. The new confocal microscope pictures readily distinguish coiled bodies from other nuclear bodies by shape, size (up to 10 micrometers), and the presence within them of a spherical structure. In experiments, Gall and colleagues mark the cells with specific antibodies to two different proteins, coilin and Sm. Each of the two antibodies is associated with a tag that fluoresces at a distinctive wavelength. The confocal microscope detects the two different fluorescent markers simultaneously. The resulting pictures show, by arbitrary colors, the distribution of each protein separately and together. The photograph (below) shows that coilin is in the coiled body itself but not in the small, associated structures, while Sm occurs in all the visible structures. There is no coilin in the spherical inclusion inside the coiled body, but there is Sm. The experiments allowed Gall and colleagues to conclude that coilin is important for the maturation of particular mes-

A coiled body from a Xenopus oocyte, photographed by Joe Gall and Michel Bellini at the Department of Embryology. Panel e shows a coiled body with one internal and three attached associated structures called snurposomes, photographed by differential interference contrast. Panels f—h shows the same field imaged with the confocal microscope. The coiled body is stained for both coilin (green) and Sm (red) proteins. Because these proteins fluoresce at different wavelengths, the confocal microscope can detect them simultaneously. In h, they are co-localized. (Reprinted from Mol. Biol. Cell 9, 2987-3001, with permission.)

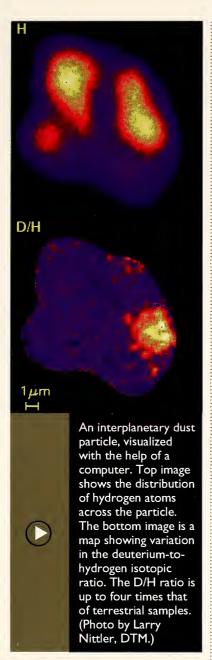
senger RNAs that encode proteins called histones, a process known to occur in the coiled bodies.

"Seeing" what is not light at all. Computers display radiation by converting digital data into images, regardless of where in the electromagnetic spectrum the light waves originate. Computers can also construct images from data that have nothing whatever to do with light, as long as the data represent a scan over a surface or a body. Such pictures are not what we usually mean when we think of "seeing," that is, the perception of a distribution of light.

In Erik Hauri's studies of volcanic rocks at DTM, the focus is on tiny inclusions that originated in magma from Earth's fluid interior mantle. Conel Alexander is interested in special small inclusion grains in meteorites; these presolar grains represent material formed before the sun and planets took shape. Both scientists use an extraordinary new instrument, which produces beams of ions that sweep across a rock's surface and shoots tiny samples from precise locations on the surface into a mass spectrometer for determination of chemical and isotopic composition. Computers run the ion microprobe and the mass spectrometer, as well as the connection between the two. Computers also collect and store the raw data, and calculate visual maps of the abundance of the different atoms and isotopes across the surface, all on a scale of micrometers. Visualization of the data yields an appreciation of its significance which would otherwise be difficult to perceive.

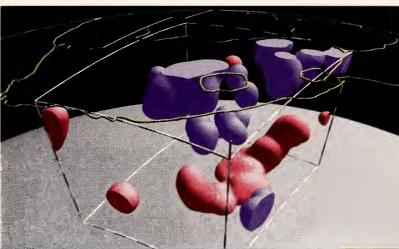
Not long ago, we could not even imagine seeing the inner structure of a living human brain. Tomography, a consequence of the computational power of computers, has changed that. The word originally referred to an x-ray scan at a chosen plane through a living brain. Computers are necessary to perform the complex mathematical calculations that convert the scanned data to cross-sectional pictures. Such tomographic images show concentrations of structures as areas that are electron dense or deficient. Seismic data, too, can be visualized by converting them into a seismic tomograph, a picture of the distribution of particular properties, such as seismic velocity, in a cross-section or column of the Earth's interior (see, for example, Sean Solomon's essay in Year Book 96/97).

At the Geophysical Laboratory, Yingwei Fei, Constance Bertka, and Larry Finger experiment with materials believed to be in the iron-rich cores of Earth and Mars. Iron is surely present and sulfur may also occur, accounting for densities known to be less than that of pure iron. Better estimates of the temperatures in the planets' cores depend on understanding the nature of the ironsulfur compounds that may be present. In their recent experiments, these scientists used x-rays to map the distribution of iron and sulfur over samples ranging from 25 to 50 micrometers in size. The mixtures had been treated at high temperature (over



800°C) and pressure (10 gigapascals and higher). The data were converted into false-color maps showing the distribution of metallic iron (Fe), iron sulfide (FeS), and, at 14 gigapascals, an unexpected intermediate, Fe₃S₂. The images thus made it possible to "see" the three materials and their juxtaposition in melted and unmelted samples.

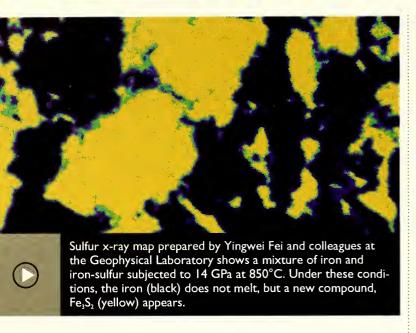
Molecules would probably be visible, and may one day be so, if sufficiently powerful microscopes could be built. But for now, in spite of the fact that molecules are everywhere, we can't see them directly and in detail. Students used to be introduced to molecules through two-dimensional and later three-dimensional schematic drawings in textbooks. Rarely were the diagrams accurate descriptions of the relative sizes of the atoms, the lengths of the



Three-dimensional image of seismic velocity anomalies in the Earth's mantle beneath southern Africa, modeled by former DTM fellow John VanDecar from a computer-generated tomographic inversion of seismic data. The material with the highest velocity is enclosed in blue regions, the lowest in red. (The gray sphere underlying the model is at 1000-km depth; the yellow lines at the surface represent political borders.) The high-velocity anomalies near the top of the mantle (100-km depth) lie beneath ancient Archean cratons. The low-velocity anomaly at the bottom of the model may correspond to the upper part of the low-velocity anomaly seen in lower-resolution global tomographic images, and may represent a large-scale, buoyant upwelling of the deep mantle (see pp. 66).

bonds between them, or the space they filled. The illustrations were further limited by the inability to show very large molecules. Even 100 atoms were a challenge to the artist and the budget manager for the book or journal. That was the past. Today, students and working scientists routinely see images of even huge protein molecules on computer screens or printed pages. Everything is three-dimensional, and color coding emphasizes different aspects of the structure. On a computer screen, the molecules can be turned every which way at will. Different views show distinct aspects of the molecules. It is even routine to view two interacting molecules, for example an enzyme and its substrate, and evaluate the "fit" between them. Investigators in search of drugs or inhibitors of particular enzymes can try out the "fits," tweak the structures, try again, and thus come to a rational decision about what kinds of substances are worth synthesizing in the laboratory.

Here, again, the input digitized data do not originate in images. Massive tabulations of fundamental information on the size of atoms and the length and directions of bonds between particular kinds of atoms are mined. This information, together with data on how crystalline forms of the material scatter x-rays, is fed into powerful computational pro-

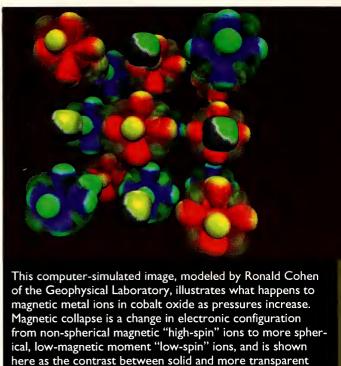


grams. The end results are elegant sculptures of three-dimensional molecules containing a few or thousands of atoms.

BEYOND OUR SENSES

Science and technology have for centuries expanded human competence beyond the limits imposed by biological capacities. By now, the abilities to float, fly, explore the deep sea with submarines or the shallows with scuba gear are so accessible that they are recreational as well as scientific and commercial activities. These technologies all extend human physical capabilities. Enhancements of the human senses are of more recent origins. Radio and telephones enable our species to hear sounds otherwise out of reach of our ears. Movies, television, and now the internet, let us see light originating out of sight of our eyes.

This essay has described extraordinary ways through which novel images have, in the last decade, enabled new science. Carnegie Institution scientists, like their most productive colleagues in other institutions, have been quick to adopt and adapt the innovative technologies. Scientists should now recognize that the general public will also respond enthusiastically to these marvelous pictures. Imaging tools represent a very special opportunity to improve public understanding of and confidence in science.



areas. The colors represent the local magnetic moments

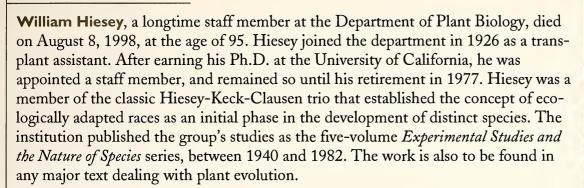
(spin density.)

A great deal of evidence confirms that the public-atlarge has only a minimal knowledge of modern and even not-so-modern scientific insight into the natural world. Yet, we also know that many people are interested in science. The Discovery Channel thrives. Millions connected to NASA's web site when Pathfinder's robot roamed Mars. Congress this year gave a \$2 billion boost to the NIH budget. Each month almost 400 people fill the Root Auditorium in Carnegie's administration building to hear a Capital Science lecture. Together, the high interest and yet lack of understanding suggest a failure in communication. Scientists speak and write. The public listens and reads, but only occasionally comprehends. It finds scientists' beloved charts, tables, and graphs confusing and dry. But people readily remember images. The new imaging power can be a key to enhanced public understanding.

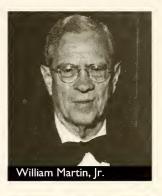
Centuries ago, the invention of the telescope revealed the moons of Jupiter and focused minds on the universe beyond Earth. Later, the microscope uncovered the unsuspected world of microbes and cells, engendering new wonder at the natural world. "Seeing is believing" is a phrase that does not wear out. Science has new and marvelous things to show.

LOSSES

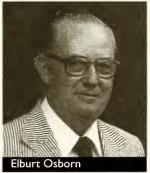
Former trustee William McChesney Martin, Jr. died on July 27, 1998. He was 91. Mr. Martin served a 16-year term as trustee (1967-1983) and three years as chairman of the board (1974-1976), remaining a trustee emeritus until his death. He is most remembered by the public for his role as chief of the Federal Reserve Board, from 1951 to 1970, the longest-held tenure in that position since 1913. Little known is that he earlier served as the first salaried president of the New York Stock Exchange and later, after service in World War II, he was the president of the Export-Import Bank.



Elburt Osborn, former staff member and distinguished professor of the Geophysical Laboratory, died on January 19, 1998, at the age of 87. Osborn was an internationally recognized authority on petrology, mineral technology, and mineral education. He joined the Lab in 1938 and remained there until 1945, when he became dean of the College of Mineral Industries at Penn State University. He went on to direct the Bureau of Mines and, finally, returned to Carnegie in 1973 as distinguished professor. Although he retired in 1977, he retained emeritus status until 1983, when he returned to Penn State to continue research.







Norman Heydenburg, a DTM staff member from 1935 until 1962, died on March 20, 1998, in Tallahassee, Florida at the age of 90. Heydenburg was involved in work measuring the nuclear component of the force between proton and proton, demonstrating that the proton-proton force was identical to the neutron-proton force, a theory that has remained the basis for all nuclear structure theory. He later worked with Merle Tuve on the proximity fuze.

James W. Boise, former bursar of the Carnegie Institution, died on April 29, 1998, at the age of 72. Boise began his career with the institution in 1952 as an accountant. In 1960 he was appointed bursar, and he remained in that position until his retirement in 1984. Boise was instrumental in developing the institution's retirement plan.

Charles Little, electronics and machine specialist at DTM from 1940 until 1977, died on December 10, 1997.

Sherman Johnson, hired in 1955 as a chauffeur at P Street and retired in 1990 as payroll supervisor, died on June 4, 1998.

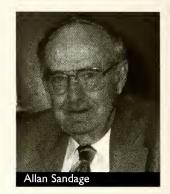
Mary Coffeen, who spent 32 years as research assistant and librarian at the Observatories (1932-1964), died in March 1998.

Milton Taylor, DTM instrument maker (1970-1983), died on January 12, 1998, at the age of 80.

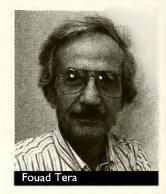
David Weinrib, DTM fiscal assistant since 1988, died on September 14, 1998, at the age of 75.

RETIRING

Two long-time staff members retired this year, and both remain at their respective departments as staff members emeriti. Allan Sandage began his appointment as staff member at the Mount Wilson and Palomar Observatories in 1952, three years after he arrived on Santa Barbara Street as a Caltech graduate student. He spent the rest of his career at the Observatories, contributing to a wide range of subjects. He is perhaps most well known for his 50-year pursuit of the fundamental cosmological parameters. As Gus Oemler writes in his essay (see p. 47), Allan has had a profound influence on several generations of astronomers. He officially retired on September 1, 1997.



Fouad Tera, a staff member at DTM for 20 years, retired on December 31, 1997. Tera is known for his innovative applications of analytical chemistry to a variety of geo- and cosmochemical topics, including defining the age of the Earth and Moon, detecting ¹⁰Be in island arc volcanic rocks (thereby proving the deep subduction of surface sediments), and providing a high-precision time scale for meteorite and planetesimal formation.



Also retiring this year was Las Campanas resident scientist **Wojciech Krzeminski**. Krzeminski first came to the Observatories in 1992. He also served as administrator of the Las Campanas Observatory for several periods. His research focused on the properties of close binary stars.

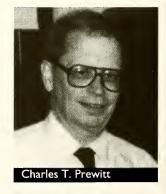
Michael Seemann, design engineer-mechanical, retired from DTM on July 1, 1998, after nearly 40 years of service. He participated in the development of many new scientific instruments, especially in the area of seismology, and was for many years responsible for the smooth operation of the DTM campus.

Mary Eileen Hogan, senior technician at the Department of Embryology, officially retired in April 1997 after 23 years of service, but she remains at the department as an employee of Howard Hughes.

Joe Vokroy retired on January 31, 1998, after 19 years as facilities manager at the Department of Embryology.

Charles Townes became a trustee emeritus in May 1998. He has been a trustee since 1965.

Charles T. Prewitt stepped down as director of the Geophysical Laboratory after 12 years of service. He remains a member of the scientific staff. During his tenure as director, he led the Laboratory to world-class recognition in high-pressure physics research.

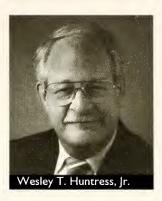


GAINS

Euan Baird, chairman of the board, president, and CEO of Schlumberger Limited, was elected a trustee of the Carnegie board of trustees at the board's May 1997 meeting. Baird joined Schlumberger, an international technical service company to the oil industry, in 1960 as an engineer, after receiving an MA in geophysics from Cambridge University. He worked in various capacities before assuming his present position in 1986.



Wesley T. Huntress, Jr. was appointed director of the Geophysical Laboratory, beginning his tenure on September 28, 1998. Before joining Carnegie, Huntress had been NASA's associate administrator for space science, responsible for programs in astrophysics, planetary exploration, and space physics. Previously, from 1990 until 1993, he was director of NASA's Solar System Exploration Division and, from 1988 to 1990, he was special assistant to the director of the Earth Science and Applications Division. From 1968 until 1988 he was a research scientist at Caltech's Jet Propulsion Laboratory. Huntress, who studies fundamental chemical processes in comets, planetary atmospheres, and the interstellar medium, will be involved in the astrobiology program at the Laboratory.



Louis Ho is a new staff associate at the Observatories. Ho, who received his Ph.D. from Harvard University, studies active galactic nuclei, emission-line galaxies, supernovae, extragalactic star formation, and young star clusters.

Two new staff associates joined the Department of Embryology in July 1998. Jimo Borjigin (Ph.D., Tohoku University) studies the vertebrate brain. Erika Matunis (Ph.D., Northwestern University) studies *Drosophila* spermatogenesis.

HONORS

DTM's **George Wetherill** was elected to membership in the American Philosophical Society in April 1998. He received a National Medal of Science from President Clinton on December 16, 1997.

DTM director **Sean Solomon** was selected to receive the 1999 Arthur L. Day Prize and Lectureship of the National Academy of Sciences. Solomon will be the third Carnegie recipient of this prize, which is named after the founding director of Carnegie's Geophysical Laboratory. (The Geophysical Laboratory's Hatten S.Yoder, Jr. and David Mao received the prize in 1972 and 1990, respectively.)

Asteroid 5726, discovered January 24, 1988 by Carolyn and Eugene Shoemaker, was named "Rubin" by them in April 1997 in honor of DTM's **Vera Rubin**. Rubin delivered the Halley Lecture at Oxford University on May 19, 1998. She was awarded an honorary D.Sc. by Ohio State University at its September 1998 commencement.

Minor planet 7225 was named in honor of **Wesley Huntress**, new director of the Geophysical Laboratory, in recognition of his leadership at NASA. He was also given the second Carl Sagan Award by the American Astronautical Society. He delivered the Carl Sagan Memorial Lecture in November 1998. He was also elected president of the American Astronautical Society and was recently appointed a distinguished visiting scientist at Caltech's Jet Propulsion Laboratory.

Christopher Somerville, director of the Department of Plant Biology, was awarded an honorary D.Sc. From the University of Wageningen in the Netherlands in March 1997.

Chen-Ming Fan, staff member at the Department of Embryology, received a Damon Runyon Scholar Award.

DTM's Paul Silver and Steve Shirey were elected fellows of the Geological Society of America in May and October, 1997, respectively.

Robert Hazen of the Geophysical Laboratory received the Elizabeth Wood Science Writing Award at the July 1997 meeting of the American Crystallographic Association.

PAGE 18 YEAR BOOK 97-98

Marilyn Fogel of the Geophysical Laboratory was selected to be a 1999 Loeb Fellow of the Smithsonian Environmental Research Center. The Loeb Fellowship, inaugurated this year, recognizes accomplishments in applying physical science research tools to ecological problems.

Observatories staff associate Louis Ho received the 1998 Robert J. Trumpler Award from the Astronomical Society of the Pacific, given for outstanding dissertation research in astronomy.

Geophysical Lab's Charles T. Prewitt was honored at the Fall 1997 meeting of the American Geophysical Union with a special symposium. The twelve "Prewitt sessions" focused on aspects of mineralogy and crystallography to which Prewitt has made significant contributions.

Hatten S. Yoder, Jr., director emeritus of the Geophysical Lab, received the 1998 History of Geology Award at the Geological Society of America's annual meeting, and was the 1998 Distinguished Scientist Lecturer at the Forum for the History of Science in America.

High school students Caleb Fassett and Andrew Waterman, summer interns at DTM, were named semi-finalists in the Westinghouse Science Talent Search in January 1998. Their reports were based on their internships with John Graham and Vera Rubin, respectively. In July 1998, Fassett won seven awards at the Montgomery Area Science Fair.

Former Embryology staff member Robert DeHaan (now at Emory University Medical School) received the Thomas Jefferson Award from Emory University. In December 1998, he received the Bruce Alberts Award for Distinguished Contributions to Science Education from the American Society for Cell Biology.

Munir Humayun, a former Barbara McClintock Fellow at DTM now at the University of Chicago, received the Clarke Medal of the Geochemical Society in August 1998.

Lars Stixrude, former postdoctoral associate and visiting investigator at the Geophysical Lab, received the 1998 Macelwane Medal of the American Geophysical Union.

Maxine Singer received the 1998 Georgeanna Seegar Jones Award in June 1998 for Lifetime Achievement in Women's Health Research. She received the Outstanding Educator Award from San Francisco's Exploratorium at its 21st annual awards dinner in May 1998.

Trustee William Golden received an honorary degree from the Graduate School and University Center, City University of New York.

Gary Ernst was awarded the first Geological Society of Japan Medal at the Society's annual meeting in Tokyo on March 28.

Frank Stanton received an honorary degree of Doctor of Humane Letters from Muhlenberg College in May 1998.

Frank Press was awarded the Lomonosov Medal of the Russian Academy of Sciences, its highest award.

Charles Townes was elected to the National Academy of Engineering.

CORPORATIONS AND FOUNDATIONS

\$100,000-\$1 million

Anonymous Arnold and Mabel Beckman Foundation The Morris and Gwendolyn Cafritz Foundation Damon Runyon-Walter Winchell Foundation DDI Corporation Philip L. Graham Fund Howard Hughes Medical Institute Johnson & Johnson W.M. Keck Foundation Kyocera Corporation Martek Biosciences Corporation The G. Harold and Leila Y. Mathers Charitable Foundation Andrew W. Mellon Foundation The Ambrose Monell Foundation The Pew Scholars Program The Starr Foundation The Thomas N. Urban, Jr. and Mary Bright Urban Foundation

\$10,000 to \$99,999

Sidney J. Weinberg, Jr. Foundation

Abbott Laboratories Fund Fundacion Andes The Bristol-Myers Squibb Foundation, Inc. Carnegie Institution of Canada/Institution Camegie du Canada Charter Oak Partners Exxon Education Foundation Fannie Mae Foundation Golden Family Foundation Humana, Inc. Suzanne and David Johnson Foundation. Samuel H. Kress Foundation The John Merck Fund The Ralph M. Parsons Foundation The Pfizer Foundation, Inc. Prince Charitable Trusts The Ruth and Frank Stanton Fund The Helen J. Urban & Thomas N. Urban, Sr. Charitable Foundation

\$1,000 to \$9,999

Wilmer, Cutler & Pickering

Bell Atlantic Foundation
Crestar Foundation
Richard W. Higgins Foundation
Paul and Annetta Himmelfarb
Foundation
Human Genome Sciences, Inc.
Gerald D. Laubach Fund
Mendel Biotechnology
Miller Anderson & Sherrerd, LLP
Newmont Mining Corporation
Primecap Management Company
Nina and Ivan Selin Family
Foundation

Under \$1,000

Berkshire Hathaway Inc.
The Charlotte and Gary Ernst Fund

INDIVIDUALS

\$100,000 to \$1 million

Anonymous Kazuo Inamori Michael and Mary Gellert

\$10,000 to \$99,999

Philip H. Abelson
Mary Anne and G. Leonard
Baker, Jr.
John and Susan Diekman
Lois Severini and Enrique Foster
Gittes
Mr. and Mrs. Robert G. Goelet
Robert and Margaret Hazen
Richard E. Heckert
John D. Macomber
Gilbert and Jaylee Mead
Burton J. and Deedee McMurtry
Evelyn Stefansson Nef
Robert J. and Vera C. Rubin
Dan and Maxine Singer

\$1,000 to \$9,999

L. Thomas and Margaret G. Aldrich Anonymous Donald D. and Linda W. Brown John F. Crawford Howard C. and Eleanora K. Dalton Edward E. David, Jr. Gordon and Alice Davis John Diebold lames and Alma Ebert Jo Ann Eder Andrew Fire Susanne E. Garvey Pembroke J. Hart Professor Ulrich Heber Charles C. and Mary B. James Jr. Robert Jastrow Paul N. Kokulis Marlow V. Marrs Chester B. and Barbara C. Martin, Jr. John McStay Richard A. and Martha R. Meserve Alvin E. and Honey W. Nashman Frank Press Allan Sandage Allan Spradling David F. Swensen

Under \$1,000

Paul A. Armond, Jr. Jagannadham Akella Walter Beach Bradley F. and Virginia W. Bennett Walter G. and Shirley A. Berl Giuseppe and L. Elizabeth Bertani Hans and Rose Bethe Daniel and Debrah Bogenhagen Jeanette and Walter Brown Gordon Burley Donald M. Burt Alice and Peter Buseck Zhou Wang and Xiaoyan Cai John A. R. Caldwell Dana Carroll James F. Case Britton Chance King-Chuen Chow Robin Ciardullo Harriet B. Creighton John R. and Muriel H. Cronin Sandra K. Dalsheimer Igor B. and Keiko Ozato Dawid Vincent De Feo Robert L. DeHaan John and Ruth Doak Bruce R. Doe William H. Duncan Dorothy Ruth Fischer Michael and Helen Fleischer Barry Ganapol M.Charles and Mary Gilbert Kirsten and Oliver Gildersleeve, Jr. Richard and Irene Grill Necip Guven Helen M. Habermann William and Dorothy Hagar Stanley R. Hart William K. Hart Robert J. Hay Heinz Tiedemann H. Lawrence Helfer John and Ann Hess Satoshi Hoshina Haifan Lin and Edna I. Hu Kenzo Yagi Mark E. and Peggy A. Kidwell Olavi Kouvo Otto C. and Ruth Landman Arthur and Faith W. LaVelle Harold and Wei Soong Lee Harlan Lewis Steven and Nancy L'Hemault Dan L. Lindsley Charles A. and Elizabeth Little Felix I. Lockman Eric Long Dr. Richard A. Lux Anthony P. Mahowald Steven R. Majewski James M. Mattinson Sheila McCormick Steven L. McKnight Gisela Mosig Norio Murata lack E. Myers John P. de Neufville Kevin O'Hare T. S. Okada George Pepper R. P. Ranganayaki Douglas and Anne ReVelle Philippe Reymond Carl R. Robbins Glenn C. Rosenquist Selwyn and Pamela Sacks

Martin and Marilyn Seitz

Nobumichi Shimizu

The Carnegie Institution received gifts and

Edwin and Virginia Shook Douglas K. Struck Linda L. Stryker Lawrence A. Taylor Ian Thompson Norbert and Roslyn Thonnard Elwood O. and Doris E. Titus Scott B. Tollefsen Charles H. Townes William Upholt and Mary Lee Morrison Larry N. Vanderhoef David Velinsky Hemming J. Virgin John and Paula Wehmiller James A. Weinman Charles Yanofsky Violet K. Young

GOVERNMENT

More than \$1 million

National Aeronautics and Space Administration National Institutes of Health National Science Foundation Space Telescope Science Institute

\$100,000 to \$1 million

U.S. Department of Agriculture U.S. Department of Energy U.S. Office of Naval Research

\$10,000 to \$99,999

Smithsonian Institution National Institute for Global Environmental Change

OTHER

\$100,000 to \$1 million

Nagoya University

\$10,000 to \$99,999

American Cancer Society
Biosphere Two Center, Inc.
Incorporated Research Institutions
For Seismology
International Human Frontier
Science Program
Mariah Associates, Inc.
University of Italy
University of Tokyo

\$1,000 to \$9,999

American Society of Plant Physiologists Fund For Astrophysical Research Medical Research Council of Canada Texas Historical Commission



Thinking is a Field Trip

I DO NOT KNOW WHAT I MAY APPEAR TO THE WORLD, BUT TO MYSELF I SEEM TO HAVE BEEN ONLY LIKE A BOY PLAYING ON THE SEASHORE AND DIVERTING MYSELF IN NOW AND THEN FINDING A SMOOTHER PEBBLE OR A PRETTIER SHELL THAN ORDINARY, WHILST THE GREAT OCEAN OF TRUTH LAY ALL UNDISCOVERED BEFORE ME.

SIR ISAAC NEWTON
FROM MEMOIRS OF NEWTON, VOL. II

We have all experienced a moment, a question, the beginning of a pathway, something that draws us toward what we later recognize as understanding. It happened to me during a recent hike I took with my First Light kids along the Potomac River. Earlier in the day, the children and I had discussed what science means to them, and how they like to learn about their world. As I walked, I began to understand what they had been saying.

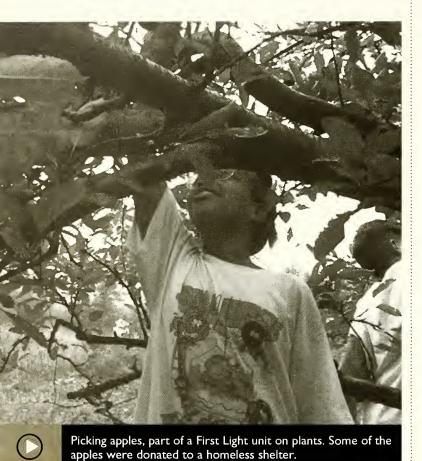
It was a crisp autumn day. We had left the designated hiking trail some time earlier. Each of the kids had now chosen his or her own path. Some children hiked alongside others, some were widely scattered, yet all were totally engaged with their surroundings. Their bodies were like so many question marks popping up over the landscape. Small pools of water, abandoned trolley tracks, a hole, a rock ledge, shells in the sediment and the creek were invitations to explore. The path each child selected was full of unknowns. All of them moved with excitement at the freedom and promise of possibility.

By selecting their own paths, each child had selected entry into a unique world of discovery. For the most part, adults lead children to places where they have already been. Children, however, prefer blazing new trails. They know that it is the new trail that fills their senses and exercises their curiosity. First Light focuses on the development of science activities that recognize children's great affinity for exploration. The Carnegie Academy for Science Education (CASE) extends these activities to the children's teachers, who learn in summertime institutes how to carry out the activities in their classrooms. In the process, many find themselves becoming like children again.

As adults, it is easy for us to believe that a child fails to think scientifically because of some short-coming. As parents, we worry when our own child seems unmotivated, or uncaptivated by any scientific subject. If we were to step back, however, and look at the choices we give our children, we might find the real answer in the paths we allow them to explore.

YEAR BOOK 97-98

Textbooks make science seem very durable and opaque, open to few questions. In truth, it is the *process* of science that is durable; the *ideas* of science are constantly evolving. But what do the children think of the science and the methods by



which they are taught? After years of teaching science and developing an intuition as to how children feel about doing science, I wanted to find out what children really had to say about science and the First Light experience. I led my kids into a simple discussion of what makes science important, and what they do that is scientific.

The results were illuminating. Children view science as simple tasks with complex possibilities. In their words, science has "easy things to do but lots of hard questions." "Whenever we do something we never seem to get to one end...it's never really finished." Mixing ingredients, measuring sand, building towers, sorting pebbles, searching under rocks, and watching life were things children said they liked to do. One child said it best: "I know how much better the stuff is to learn when no one tells me about it first. I like being the first to learn

something. It's like the teacher's always in front...always the boss." Another added that "teachers talk too much." The implications of these statements clearly challenge the cleanly choreographed science lessons we offer our children.

The basics of science and math, as currently offered by texts and worksheets, do not create real science. By prescribing paths of investigation, these formats may present a great deal of knowledge, but they encourage very little original thought. Thinking is basic to science; the freedom to think must therefore be paramount.

Science is a blend of thinking and being informed (knowledge). Thinking, said one child, is like a "field trip. You just take off and when you get someplace and look around, that's like the science." Children want to spend time exploring. At First Light, exploration has led to some interesting discoveries. One of the older participants said: "We were trying to wire the robot completely wrong. You never said a word except to say 'make sure it makes sense'—the order we were doing things. When we finished we hadn't put together the battery holder. No power!" Another chimed in that building a rock box was difficult but rewarding. "Making something for the first time is so hard...then yours comes out so neat and different even after you had to start some parts over." The freedom to think helps make the mental "field trips" that children take much more likely to result in great scientific conclusions. This helps explain why First Light is so appealing to youngsters and why, at CASE, instruction is harder than it is elsewhere: the path isn't set.

The hike along the Potomac reminded me that everything is captivating to children. Grasshoppers in billows of grass, crumbling walls, rocks, shards of old china, and absolutely anything alive. How often do we provide opportunities for exploration to our children? How important are these childhood pleasures and of what value are they to a child's developing sense of science? It seems that the diligent child who spends countless moments exploring seemingly simple tasks with great inter-

est is being very true to his or her nature. How true to that essence are our classrooms?

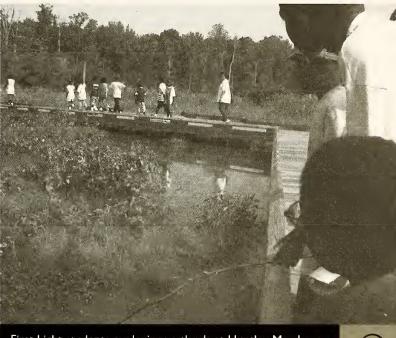
Not especially, if you listen to the children. Children believe they can understand things if they are given time. "I bet most kids could figure science out if they had money and computers and time," said one participant. "But we always are getting rushed. It takes some time to warm up. I like the activities we do that take a couple of weeks. We can go on with something we know." Children believe that the world is understandable and that each person can explore to find answers to reach understanding. The great loss to science is that this confidence disappears from the conversation of older children. As one eight-year-old said: "Science is important when you are an adult, because maybe you liked it and learned all about it when you were a kid...but my brother hates science in high school."

But how do we reconcile our adult views of science with those of our children? For children to enjoy and learn science two requirements seem crucial: time for exploration and the materials to explore. The children agreed that there were never enough materials around to use. From the children's perspective, ideal materials included "magnifying things, containers, building stuff, water, and supplies for putting things together." The children also wanted real things like "rocks, shells, teeth, and bones, but nothing dead." One comment was especially insightful. "You don't need a lot to teach with. Remember when we did that map about where pencils came from? But when we are learning science ourselves, it's fun to have a lot of stuff around."

During our hike, there were fascinating things everywhere to learn about. I was comforted that the children were so curious about what they were experiencing. But as I talked about the history of the rocks and the complexity of the local plants, I realized that most of the children didn't know how to connect the animals, plants, people, and places to their lives and hometown. As I talked on about the city at large, I realized anew that the children's world was only as far as they could see, touch, and

question. Dynamite holes and rusting relics of trolley tracks, fish bones, abandoned nests, evidence of fire, and a lost shoe became the history lessons. Each find became a mental field trip. Questions of origin and purpose connected the things we found along the river to the children's lives.

Where we find suitable materials for our thinking is largely determined by the "hikes" we are allowed to take. The trails we offer children determine the whats, hows, and whys they are challenged to answer. The paths they experience become the



First Light students exploring wetlands at Huntley Meadows Regional Park, Alexandria, Virginia.

passions that mold them mentally. This conclusion emerges from the reflection of children who have experienced science both ways—in First Light and in their classrooms. If, as they have suggested, we try letting them choose the path and hike behind them instead of always in front, than we as parents and teachers may discover the child's truth, that "thinking is a field trip."

-Charles James



THE DIRECTOR'S ESSAY:

Computers and Biology

EVERYTHING SHOULD BE MADE AS SIMPLE AS POSSIBLE, BUT NOT SIMPLER.

—ALBERT EINSTEIN (1879-1955)

When I was a teenager, my friends and I completely disassembled a car and then put it back together again to understand how it functioned. I believe that scientists will ultimately take much the same approach to understand the mechanistic aspects of life. Indeed, until he was distracted by the prospect of sequencing the entire human genome, Craig Venter, the founder of the Institute for Genome Research in Rockville, Maryland, had initiated experiments to recreate a bacterial cell from components obtained from disrupted cells. Venter's basic idea was to first learn how to recreate a living cell from its parts, and then substitute an increasing proportion of those parts with chemically synthesized components until eventually a completely synthetic cell was created. The theatrical quality of the experiment aside, Venter's approach would allow the analysis of many combinations of many different genes rather than the current practice of studying the effects of genes singly or a few at a time.

Although it is not yet possible to put a date on it, at some point in the foreseeable future we will know a great deal about the function of every gene in a bacterial or yeast cell. Shortly thereafter, we will have some degree of understanding of the function of every gene in first one, and then many, multicellular organisms. This will come about in a series of parallel discoveries. First, all the genes in a large number of organisms, from bacteria to humans, will be sequenced. This phase, which is rapidly approaching completion for many species, will afford us the complete chemical structure of all the hereditary information in these organisms. Once a gene's structure is known, a large amount of information about its function can be determined simply by comparing its nucleotide sequence (or, correspondingly, the sequence of its encoded protein) to the sequence of all other known genes or proteins. In practice, this is made possible by internet access to extremely powerful computers at national facilities. These computers are capable of rapidly comparing particular

nucleotide sequences against a database of known sequences from all manner of organisms and finding the best matches. An example of the results from such a search is shown in Figure 1, where the amino acid sequence of the alcohol dehydrogenase gene from the plant *Arabidopsis thaliana* is compared with the sequence of alcohol dehydrogenase from humans. It is readily apparent that, at many locations along the length of the primary sequence,

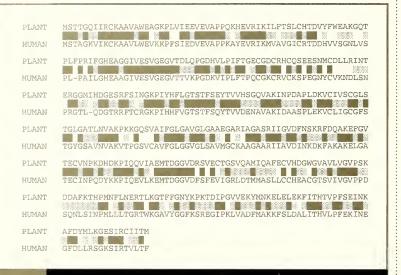




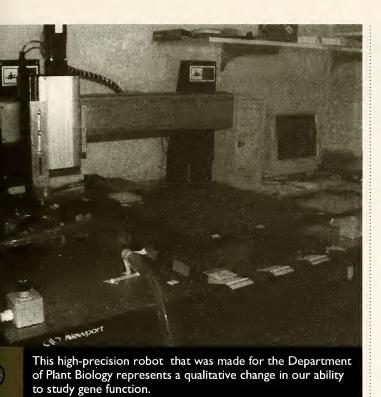
Fig. 1. Map of the amino acid sequences of the alcohol dehydrogenase gene from human and plant. The large degree of sequence identity (marked as solid) or similarity (shaded areas) implies the two genes have similar function.

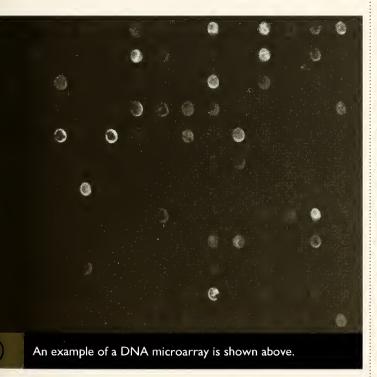
the two proteins contain the same amino acids. In contrast, two proteins of unknown function would show little or no sequence similarity, even if they came from the same organism. The fact that the two sequences have many amino acid residues in common implies that they have similar or identical function. Thus, if we were to isolate a new gene from an organism and find that the protein encoded by that gene also shared a high degree of sequence similarity with these two proteins, there would be a high probability that the new gene is also an alcohol dehydrogenase. By this and related kinds of analysis, it has been possible to assign general functions to about 40% of all the plant genes sequenced to date solely by computational methods. As more genes are studied, the proportion of genes that can be assigned function by computer analysis will expand until at some point

all genes will be assigned to a class of known function.

Unfortunately, knowing that a protein carries out a certain function usually conveys very little about what role the gene plays in the intact organism. For example, it is now estimated that of the approximately 20,000 genes in Arabidopsis, at least 1,200 are transcription factors, i.e., genes that control the expression of other genes. Knowing that a gene encodes a transcription factor, however, tells nothing about which genes it controls, nor when and where in the organism it acts. Until recently, information about when and where a gene is expressed could be obtained only by extracting RNA from source tissues in different organs or from the same tissues exposed to different environmental conditions. The RNA could then be labeled with radioactivity or a fluorescent molecule and hybridized with the gene of interest to obtain a rough quantitative measurement of the abundance of the RNA corresponding to that gene. Knowledge of the amount of mRNA is useful in understanding where and when the corresponding gene acts and what, if any, environmental factors influence its action. Because there are more than 20,000 genes in a higher plant, many different cell and tissue types, and hundreds or thousands of environmental conditions, it is not surprising that little or nothing is known about how the expression of most genes changes in response to the many possible variables.

DNA Microarrays. Recently, a new technology called DNA microarrays has emerged that offers the potential to greatly facilitate the acquisition of information about gene expression and gene function. The technology is superficially simple. For each gene in an organism, a fragment of DNA can be purified and stored in a multiwell plate consisting of a regular array of closely packed tubes each of about 20 microliters volume. A robotic arm equipped with one or more very finely machined quills is then used to transfer DNA from the wells of the storage plate onto the surface of a glass slide that has been chemically treated so that the DNA





binds to the glass. Each time the quill touches the surface of the slide, it deposits a tiny droplet of DNA as a round dot. The robot is sufficiently precise so that approximately 10,000 distinct dots of DNA can be placed within a three-square-centimeter area to produce a DNA microarray. When a solution containing fluorescently labeled total cellular mRNA is incubated with the microarray,

each of the DNA fragments binds to its cognate mRNAs; the amount of mRNA bound to a single DNA dot is proportional to the amount of the corresponding mRNA in the total mixture. Thus, by measuring the amount of fluorescence associated with each DNA dot, one can determine how much of each type of mRNA exists in a complex mixture of mRNA, such as that normally found in whole-cell extracts. The importance of this method is that it permits the simultaneous measurement of the expression of all the genes in an organism with a relatively simple procedure. This represents a qualitative change in our ability to study gene function.

DNA microarrays were invented several years ago by Dari Shalon, Pat Brown, Ron Davis, and colleagues at Stanford University. With the benefit of their generous advice, and support from the U.S. Department of Energy and the Carnegie Institution, staff member Shauna Somerville commissioned the construction of a gridding robot at the Department of Plant Biology in 1997, and



Shauna Somerville (right) and Pam Green (Michigan State University)



implemented the technology for use in understanding plant gene expression. Since that time, Shauna has become the lightning rod for interest about the technology in the plant biology community. She received more than 100 inquiries within a two-month period following a well attended symposium talk in early 1998, and has since then hosted many dozens of visitors to the department.

Although Shauna's interest in the technology is related to its use in understanding the changes in gene expression following the infection of a plant by a pathogen, she also considers it her responsibility to help the community acquire access to the technology. As part of this effort, Shauna and colleagues Pam Green, John Ohlrogge, and Ken Keegstra (Michigan State University), Michael Sussman and Rick Amasino (University of Wisconsin), Steve Dellaporta (Yale University), and Mike Cherry (Stanford) recently received a three-year, \$8.7 million grant from the National Science Foundation to make DNA microarrays and a collection of insertional mutants available to the community. The Carnegie and Michigan State groups will print DNA arrays consisting of more than 10,000 different Arabidopsis genes and provide them free of charge to the academic plant biology community. Upon request, they will also perform the hybridizations for hundreds of experiments each year. Because the instruments used to measure fluorescence are not yet widely available, they will also analyze the results of hybridizations for anyone who needs assistance. In return for providing this service, they expect to receive a copy of the data obtained from each experiment. After a short delay, they will release the data to a public database that is being developed at the Department of Plant Biology. Since each of the hundreds of users of the technology will likely be pursuing a unique question, the conditions used to make the different RNA preparations associated with the various experiments will represent a broad range of inherent possibilities. In this way, by combining the individual experiments on a common technology platform, significant progress will be made toward the goal of understanding the topology of plant gene expression.

Since each data point of each experiment will contain information on more than 10,000 genes, the computational problems associated with this approach to biology are significant. The problem is not in storing the data, but in deciding how to interrogate it. There are many different aspects to the problem, but perhaps an example will best illustrate the issues. Suppose that at some point in the future we have a database in which RNA from Arabidopsis plants subjected to 100 different treatments has been used to measure the expression of 10,000 genes over an average of five different tissues and four time points. As an example of such a treatment, we might treat a plant with a chemical that, for unknown reasons, causes an effect on growth. We would extract RNA from the plant and use it to measure the chemical's effect on the expression of all the genes. We would then compare the treatment pattern to all previously observed patterns in the database to determine if the treatment mimicked any other effect of known cause. Here is where the complexity arises. It is unlikely that an exact match will be found. Rather, each of the data sets may have some responses in common with the treated sample but other responses that don't match at all. The solution to the problem—determining which responses are informative of the underlying cause and which are not—will require the development of novel analytical tools at the interfaces of biology, computing, and mathematics. Similarly, it is already possible to envision many other kinds of experiments whose complex queries can be answered only with new computer tools.

Characterizing mutations. Yet another large-scale strategy that can be used to obtain information about the function of all the genes in an organism is to characterize a mutation in each gene. In the simplest case, this can be accomplished by insertional mutagenesis using a transposable element, such as the maize Ac element. Ideally, it should be possible to produce a large collection of insertional mutants such that for every gene in the organism at least one plant in the population has an insertion in that gene. By sequencing a few nucleotides of the DNA region adjacent to the insertional ele-



ment in each plant, and then comparing the nucleotide sequence to the complete genomic sequence, it should be possible to identify which gene had been altered in each mutant line. Since higher plants are thought to contain only about 20,000 genes, ultimately, only about 20,000 mutant lines would be required to inactivate each gene in a flowering plant such as Arabidopsis. The information on these 20,000 lines could be linked in a database to information on gene sequence and patterns of gene expression, information on the function of related genes, and finally to information on the experimentally determined phenotype of each mutant (the latter to be contributed by the world community of scientists). In the case of Arabidopsis, there are thought to be about 3,000 people working with the organism. If we assume that the analysis of each Arabidopsis mutant would require about one person/year, it seems likely that the complete analysis could be completed within the next ten years. In order to initiate this kind of analysis, Shauna's collaborators, Mike Sussman, Rick Amasino, and Steve Dellaporta, will take

responsibility for disseminating approximately 110,000 mutant lines of *Arabidopsis* containing insertional mutations. Although their distribution model does not as yet involve sequencing all the inserts, preliminary experiments by Jonathan Jones and colleagues at the Sainsbury Institute in Norwich, UK, have indicated that this would be a productive and efficient next step.

In summary, the path to some degree of comprehensive knowledge about the informational basis of various life forms is within reach. It seems likely that additional high-throughput experimental methods will be developed and will contribute other forms of information. For example, various known protein modifications, such as the phosphorylation/dephosphorylation reaction, may be amenable to high-throughput approaches. However, I believe that as the amount of information grows, and as the sophistication of our computational tools improves, we will find an increasing number of experiments driven not by direct observations of an organism but by computer-gen-

YEAR BOOK 97-98

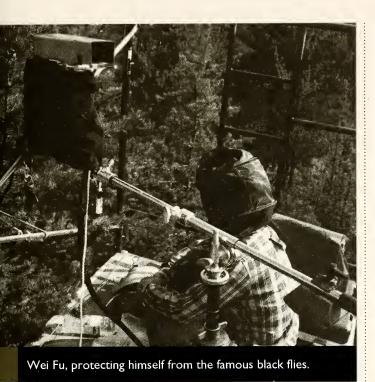


erated hypotheses. One last gedanken experiment may illustrate the point.

The available evidence suggests that genes encoding proteins which act together in some fashion have a common mode of regulation, i.e., they form a regulon. Thus, it seems likely that if one measured the level of expression of all the genes in a plant under a very large number of different developmental and environmental conditions, one would find that all of the genes involved in, say, lysine biosynthesis would have a pattern of regulation more similar to each other than to any gene not in the pathway. If this is generally true, then the function of many unknown genes could be discovered simply by identifying which other genes they most closely resemble based on patterns of gene expression. In all those cases where at least one gene in a regulon is of known function, the function of the other genes could be inferred. Experiments to test the proposed function could then be carried out in an efficient manner.

Computational Ecology

Carnegie staff member Chris Field has remarked that the ecological equivalent of a genome project is global ecology. Indeed, this seems an apt comparison by many criteria, including the dependence on computational methods to extract information from large volumes of data. However, whereas molecular biologists have not yet really begun to understand how cells function as molecular ecosystems, Chris, Joe Berry, and colleagues have made significant progress in developing predictive computer models for terrestrial ecosystems. Their approach has been to summarize individual plant responses to environmental variables into models that simulate ecosystem exchanges of carbon, water, and energy at the global scale. These models synthesize surface data on climate and soils and satellite data on vegetation type and canopy development, and draw functional generalizations from physiology and ecology. Ultimately, they help test hypotheses that lead to a better understanding of the future status of terrestrial ecosystems, especial-



ly the responses to and influences on such global change factors as increased atmospheric carbon dioxide (CO₂), habitat destruction, and altered climate.

Although useful models have been developed, the quest for more robust models continues. Over the past decade, Joe Berry and colleagues have developed largely mechanistic models to predict how the rates of photosynthesis and transpiration of water by leaves of higher plants are controlled by environmental conditions, such as light intensity, temperature, water availability, and CO₂ concentration. They first formulated these models at the scale of the fundamental metabolic unit, a leaf cell. They are now developing methods to apply these models at ever larger scales, with the ultimate goal of simulating the responses of forest canopies. The difficult part of this work is not in writing the models but in testing them against reality. This year, postdoctoral associate Wei Fu developed a model that simulated photosynthetic and stomatal responses of a tree canopy. He based the model on long-term measurements of real responses using

instruments placed high in a forest canopy. Photosynthesis and stomatal conductance are maximal in the early morning of each day and fall during mid-day with partial recovery during the afternoon. At night, CO₂ production by respiration continues. The result is an apparent negative rate of net photosynthesis. Wei Fu successfully simulated these responses using only information on environmental conditions experienced by the aerial parts of plants and physiological information obtained from studies of leaf responses to light intensity, temperature, and CO₂ concentration.

At a larger scale, the CASA2 biosphere model is a spatially-resolved modeling environment used to extrapolate ecophysiological and biogeochemical principles to the global scale. The CASA2 model was developed at Carnegie, the NASA Ames Research Center, and Stanford University. Its main advantage is its reliance both on satellite data (for the parameterization of its net primary production, NPP, model) and on mechanistic plant and soil carbon and nitrogen data (for the modeling of carbon flow through terrestrial ecosystems). CASA2 has been used to test the assumptions not only of current theory in the global carbon cycling community but also the usefulness of the satellite data on which it relies. The model calculates the seasonal flow of carbon between the atmosphere and the terrestrial biosphere on a number of different time steps and with a multitude of spatial resolutions. It explores relationships between different assumptions about the terrestrial biosphere and the activity of the global carbon cycle.

During the past year, Chris Field and colleagues used CASA2 and related tools to explore a number of global-scale questions. In one project, described in a paper published in *Science* (Vol. 281, pp. 237-240, 1998), the group coupled CASA2 with the VGPM ocean primary production model to develop a new estimate for total annual growth, or net primary production (NPP*), of land and

^{*}For both terrestrial and oceanic models, ϵ cannot be directly measured from space and so must be parameterized with field measurements. Marine systems can be parameterized from thousands of I°C-based field measurements of NPP. Terrestrial values are less abundant. With few exceptions, ocean NPP models estimate ϵ solely as a function of sea-surface temperature. In terrestrial ecosystems, parameters vary with ecosystem type and with stresses from unfavorable levels of temperature, nutrients, and water.

ocean plants, using satellite data and parallel algorithms for the terrestrial and marine components. The basic approach was to calculate NPP as a function of the driving energy for photosynthesis and the average light utilization efficiency ε . The driving energy for photosynthesis is the absorbed, photosynthetically active (400-to-700 nm) solar radiation (APAR). APAR depends on the amount and distribution of photosynthetic biomass as well as the fraction of downwelling solar radiation that is in the visible (photosynthetically active) wavelengths. Field et al. calculated oceanic APAR from satellite-derived measurements of surface chlorophyll (Csat). They calculated terrestrial APAR from satellite-based estimates of vegetation greenness, which is often referred to as the normalized difference vegetation index (NDVI). (Csat and NDVA are the primary sources of variability in the model.) ε is an effective photon yield for growth that converts the biomass-dependent variable (APAR) into a flux of organic compounds (NPP).

The analysis by Field and colleagues highlighted the nearly identical magnitude of total land and ocean annual plant growth, but it also pointed to important differences between land and ocean plant biology. For instance, only 7% of the photosynthetically usable radiation incident on the ocean surface is absorbed by phytoplankton, with the remainder absorbed by water and dissolved organics. In contrast, leaves of terrestrial plants on land without permanent ice cover absorb about 31% of the photosynthetically usable radiation. Although primary producers in the ocean are responsible for nearly half of the biospheric NPP, they represent only 0.2% of the global primary producer biomass. This uncoupling between NPP and biomass is a consequence of the more than three orders of magnitude faster turnover time of plant organic matter in the oceans (average 2 to 6 days) than on land (average 19 years).

Another series of studies, led by predoctoral fellow (and recent Stanford Ph.D.) Jim Randerson, used atmospheric data as a probe for terrestrial processes. Focusing on recent increases in atmospheric CO₂

concentration at high northern latitudes, Jim concluded that the patterns are consistent with increased plant growth in the temperate and boreal zones in recent years. The atmospheric patterns also imply an earlier start to the growing season, with an average shift of about four days since 1980. He found, however, that the patterns are not consistent with a recent hypothesis put forward by others—that most of the northern hemisphere sink reflects the regrowth of previously harvested forests.

Approaching recent changes in the carbon cycle from a different perspective, sabbatical visitor Ruth DeFries (University of Maryland) combined traditional vegetation maps, new satellite-based vegetation maps, and a carbon-cycle model to quantify the cumulative effect of human activities on terrestrial carbon storage and plant growth. Ruth's approach indicates that human activities have decreased terrestrial carbon storage by about 180 billion tons, or about 10% of the current total. Her concurrent estimates of changes in plant growth underscore the challenges of land management, especially in tropical climates. On average, she found that human modification of the Earth's surface has decreased annual plant growth very little, only about 5%. But the impacts are far from uniform. Across much of the tropics, for example, human-induced changes in vegetation type often decrease plant growth by more than half. Some of this reflects degradation from grazing, fuelwood harvesting, erosion, etc. But when the effects of agriculture alone are considered, the pattern is striking. In the temperate zone, total plant growth in regions converted to agriculture is usually equal to or greater than that before clearing. In the tropics, however, conversion to agriculture often decreases plant production substantially, especially in countries with the least resources to invest in land and crop management.

The future development and application of wholebiosphere models, such as those described here, can play a major role in the emergence of integrated, comprehensive perspectives on the function of

the Earth system. Measurements of NPP are critical to these efforts, because NPP is central to carbon and nutrient dynamics and links biogeochemical and ecological processes. The global carbon cycle and the ecological processes that contribute to it are not in steady state but are highly dynamic. Current capabilities to interpret these dynamics and their implications for the future of the biosphere are constrained by gaps in the data record, limitations on data quality, and incomplete understanding of some of the mechanisms. The successful launch of the <u>Sea-viewing Wide-Field-of-view</u> Sensor (Sea WiFS) in September 1997, along with other forthcoming remote-sensing missions, will provide marked improvements in the quality of APAR measurements for both land and ocean. These programs need to be paralleled by efforts to improve the characterization of spatial and temporal variations in carbon flux and to learn the fate of carbon once it is fixed in photosynthesis.

Education in Biological Computing

Unfortunately, there are very few scientists who have the level of knowledge in biology, mathematics, and computing required to develop computa-

tional tools for the new frontiers in biology. Those with the requisite skills generally elect not to work in the academic sector because of the relatively low level of compensation or because of the grudging academic recognition accorded computational biology by many bench scientists. Because of the limited employment opportunities facing recent Ph.D.s in biology (see Year Book 96/97, p. 27), I believe that support and encouragement for additional training of biologists in computer science and certain aspects of mathematics would both accelerate the growth of biological knowledge and provide rewarding career opportunities. Because Carnegie departments do not have the constraints on staff composition associated with most university departments, this is an area where the institution may be able to help catalyze the growth of a critical new discipline. During the coming year, for example, the current staff of the Arabidopsis database, AtDB (http://genomewww.stanford.edu/Arabidopsis/), will move from the Stanford medical school to the Department of Plant Biology. It is my hope that this group will find common ground with the ecological modeling groups here and that something novel will emerge from this new frontier.

-Christopher Somerville

Research Staff Members

Joseph A. Berry Olle E. Björkman Winslow R. Briggs, Director Emeritus Christopher B. Field Arthur R. Grossman Neil E. Hoffman Christopher R. Somerville, Director Shauna C. Somerville

Staff Associate

David Ehrhardt

Visiting Investigators

Charles Cockell, Bay Area Environmental Research Institute¹ Abhaya Dandekar, University of California, Davis² Ruth DeFries, University of Maryland³ Pierre Friedlingstein, Comell University Fellow² Michihiko Kobayashi, University of Kyoto⁴ Russell Malmberg, University of Georgia⁵ Philippe Reymond, University of Lausanne⁶ Jean-David Rochaix, University of Geneva7 Kosuke Shimogawara, Teikyo University8 Hans Thordal-Christensen, Royal Veterinary & Agricultural University, Denmark⁹ Daniel Vaulot, Centre National de la Recherche Scientifique, Roscoff, France¹⁰ Donald Weeks, University of Nebraska-Lincoln¹¹

Carnegie Fellows (Senior)

Luc Adam, DOE Research Associate14

In-Seob Han, University of Ulsan, Korea (2) Young Mok Park, Korea Basic Science Institute¹³

Postdoctoral Fellows and Associates

Timothy Ball, NASA Research Associate¹⁵ Devaki Bhaya, USDA Research Associate¹⁶ Pierre Broun, DOE Research Associate¹⁷ John Mackie Christie, NSF Research Associate Gregory D. Colello, NASA Research Associate18 John P. Davies, USDA Research Associate¹⁹ Wei Fu, NASA Research Associate In-Seob Han, NSF Research Associate20 Niall Hanan, DOE Research Associate21 Eva Huala, NSF Research Associate Jorg Kadak, DOE Research Associate David M. Kehoe, NSF Research Associate James Keddie, DOE Research Associate²² Wolfgang Lukowitz, Human Frontier of Science Fellow Michelle Nikoloff, NSF Fellow Joseph P. Ogas, DOE Research Associate²³ Dana L. Parmenter, DOE Research Associate²⁴ Marsha Pilgrim, Camegie Fellow²⁵ Seung Rhee, Camegie Fellow²⁶ Miguel Ribas-Carbo, Camegie Research Associate²⁷ Todd Richmond, DOE Research Associate²⁸ Matthias Rillig, Camegie Research Associate²⁷ Anne Ruimy, DOE Research Associate² Wolf-Ruediger Scheible, DFG Fellow Danja Schuenemann, DFG Fellow Rakefet Schwarz, Carnegie Fellow²⁹ Rebecca Shaw, Hollander Fellow³⁰

Susan S. Thayer, NSF Research Associate Margaret Tom, Mellon Research Associate²⁰ Chao-Jung Tu, Carnegie Research Associate31 Lori van Waasbergen, NSF Fellow³² Per Villand, Carnegie Research Associate33 John Vogel, NIH Fellow34 lain Wilson, USDA Research Associate James Zhang, DOE Research Associate35

Predoctoral Fellows and Associates

Sean Cutler, Stanford University Dafna Elrad, Stanford University Stewart Gillmor, Stanford University Claire Granger, Stanford University Laura Hoffman, Stanford University Geeske Joel, Stanford University Chris Lund, Stanford University Margaret Olney, Stanford University Johanna Polsenberg, Stanford University lim Randerson, Stanford University Seung Rhee, Stanford University² Céline Schiff, National Institute of Agronomy, Paris, France²⁰ Patrick Sieber, University of Fribourg36 Chris Still, Stanford University Dennis Wykoff, Stanford University

Support Staff

Pinky Amin, Laboratory Technician Cesar R. Bautista, Horticulturist Elena Bolchakova, Laboratory Technician37 Kathryn Bump, Administrative Assistant Vittoria Canale, Laboratory Technician38 Catherine Chase, Laboratory Assistant39 Sohaila Dar, Laboratory Assistant⁴⁰ Manisha Dabke, Laboratory Assistant⁴¹ Nadia Dolganov, Research Associate Patrick Eiken, Laboratory Technician42 Beverly Fang, Laboratory Assistant¹² Melissa Flanigan, Laboratory Assistant⁴³ Glenn A. Ford, Laboratory Manager David Faulkner, Laboratory Assistant²⁵ Melissa Flanigan, Laboratory Assistant¹³ Anthony Gallego, Laboratory Assistant³⁶ Greg Hallock, Greenhouse Assistant44 Anjali Katrekar, Laboratory Assistant²⁵ Scott Kaufmann, Laboratory Technician!9 Clara Liang, Laboratory Assistant³⁶ Adam Lowry, Laboratory Technician Barbara March, Bookkeeper Heather McGeory, Laboratory Assistant⁴⁵ Tracy Meyer, Laboratory Assistant⁴⁶ Eriko Miura, Laboratory Technician²⁷ Barbara Mortimer, Laboratory Technician Frank Nicholson, Facilities Manager Marc Nishimura, Laboratory Technician⁴⁷ Lisa Onaga, Laboratory Assistant⁴⁶ Julie Osborn, Laboratory Technician49 Kalpana Pachipala, Laboratory Assistant¹⁶ Kenya Pinder, Laboratory Assistant^{so} Patti Poindexter, Laboratory Technician Prorseut Por, Laboratory Assistant⁵¹ Hector Pulido, Dishwasher52 Pedro F. Pulido, Maintenance Technician Thomas Robertson, Laboratory Assistant³⁶

Adrienne Roeder, Laboratory Assistant

Eric Rosenthal, Laboratory Assistant⁵³

Connie K. Shih, Senior Laboratory Technician Sonia Siyan, Laboratory Assistant Kerrin Small, Laboratory Assistant⁵⁴ Mary A. Smith, Business Manager, Gayathri Swaminath, Laboratory Technician55 Donna Sy, Laboratory Assistant⁵⁶ Joseph Thayer, Laboratory Assistant⁵⁷ Ann Tornabene, Laboratory Technician58 Ann Van, Laboratory Assistant Nhu-An Vo, Laboratory Assistant⁵⁹ Liping Wang, Laboratory Assistant60 Susana Wang, Laboratory Assistant Patrick Warren, Dishwasher62 Rudolph Warren, Maintenance Technician Aida E. Wells, Secretary Brian M. Welsh, Mechanical Engineer Diana Wiszowaty, Laboratory Assistant⁶³

From January 14, 1998 to March 31, 1998 ²To December 31, 1997 ³From June 26, 1998. ⁴From November 15, 1997 ⁵From July 1, 1997 to December 31, 1997

From July 1, 1997 to September 29, 1997

⁷From December 31, 1997 to June 30, 1998 ⁸From June 8, 1998

From August 8, 1997 to July 15, 1998 From December 15, 1997

From November 3, 1997 to June 30, 1998 Errom July 1, 1997

"From January 1, 1998 to June 20, 1998 "To November 30, 1997

15 From November 1, 1997 to May 31, 1998

From September 16, 1997

To August 24, 1997

18 To September 30, 1997

19 To January 31, 1998

²⁰ From March 1, 1998

²¹ From April 1, 1998 to June 30, 1998 ²² From July 1, 1997 to September 15, 1997 ²³ To June 15, 1998

24 From April 13, 1998

25 To August 31, 1997

²⁶ To June 30, 1998 ²⁷ From February 1, 1998 ²⁸ From April 10, 1998

²⁹To June 20, 1998

*From October 13, 1997

From April 1, 1998 From October 1, 1997

35 From January 1, 1998

4 From December 1, 1996

¹⁵ To August 22, 1997

³⁶From June 29, 1998 ³⁷From March 23, 1998

³⁸ To March 31, 1998

"From June 11, 1998

From January 5, 1998 From October 15, 1997 to January 15, 1998 From July 15, 1997 to May 29, 1998

43 From June 15, 1998

*To October 15, 1997 From October 23, 1997
To October 31, 1997

⁹ To September 19, 1997

*From May 26, 1998

From August 18, 1997 to June 5, 1998. From October 21, 1997

51 From February 24, 1998

⁵² From July 7, 1997

53 From April 3, 1998

To September 15, 1997 From September 1, 1997

56 From January 12, 1998

From July 15, 1997 to August 31, 1997
From August 18, 1997 to October 15, 1997
To December 15, 1997

⁶¹ From July 21, 1997 ⁶² To July 3, 1997 ⁶³ From March 16, 1998

- Here updated through December I, 1998. Reprints are available at no charge from the Department of Plant Biology, 260 Panama St., Stanford, CA 94305. Please give reprint number(s) when ordering.
- 1336 Bhaya, D., R. Schwarz, and A. Grossman, Molecular responses to environmental stress, in Ecology of Cyanobacteria: Their Diversity in Time and Space, M. Potts and B. Whitten, eds., Kluwer Academic Press, New York, 1998.
- 1401 Bhaya, D., N. Watanabe, T. Ogawa, and A. R. Grossman, The role of rpoF in motility and pili synthesis in the cyanobacterium Synechocystis sp. Strain Pcc 6803, Proc. Natl. Acad. Sci. USA 95,
- 1388 Björkman, O., and K. Niyogi, Xanthophylls and excess-energy dissipation: a genetic dissection in Arabidopsis, in Proceedings of the XI International Congress on Photosynthesis, G. Garab and J. Puszati, eds., Kluwer Academic Publishers, 1998.
- 1339 Botella, M. A., M. J. Coleman, D. E. Hughes, M. Nishimura, J. D. G. Jones, and S. Somerville, Map positions of 50 Arabidopsis sequences with sequence similarity to disease resistance genes, Plant J. 12, 1197-1211, 1997.
- 1368 Broun, P., S. Boddupalli, and C. R. Somerville, A bifunctional oleate 12-hydroxylase: desaturase from Lesquerella fendleri, Plant J. 13, 201-210, 1998.
- 1403 Broun, P., Shanklin, J., Whittle, E., Somerville, C.R., Catalytic plasticity of fatty acid modification enzymes underlying chemical diversity of plant fatty acids. Science, 282 1315-1317, 1998.
- 1374 Casper-Lindley, C., and O. Björkman, Fluorescence quenching in four unicellular algae with different light-harvesting and xanthophyllcycle pigments, Photosyn. Res. 56, 277-289,
- 1350 Colello, G. D., C. Grivet, P. J. Sellers, and J. A. Berry, Modeling of energy, water, and CO₂ flux in a temperate grassland ecosystem with SiB2: May-October 1987, J. Atmos. Sci. 55, 1141-1169, 1998.
- 1340 Davies, J. P., and A. R. Grossman, Responses to macronutrient deficiencies, in Molecular Biology of Chlamydomonas: Chloroplasts and Mitochondria, J.-D. Rochaix, M. Goldschmidt-Clermont, and S. Merchant, eds., pp. 613-635, Kluwer Academic Press, New York, 1998.
- 1406 Davies, J. D., and A. R. Grossman, The use of Chlamydomonas as a model algal system for genome studies, J. Phycol., in press.
- 1377 Dolganov, N., and A. R. Grossman, A polypeptide with similarity to phycocyanin; a subunit phycocyanobilin lyase involved in degradation of phycobilisomes, J. Bacteriol., in press.
- 1348 Field, C. B., J. G. Osborn, L. L. Hoffman, J. F. Polsenberg, D. D. Ackerly, J. A. Berry, O. Björkman, A. Held, P. A. Matson, and H. A. Mooney, Mangrove biodiversity and ecosystem function, Global Ecol. Biogeog. Lett. 7, 3-14, 1998.

- 1394 Franck, V. M., B. A. Hungate, F. S. Chapin, III, and C. B. Field, Decomposition of litter produced under elevated CO₂: dependence on plant species and nutrient supply, *Biogeochemistry 36*, 223-237, 1997.
- 1409 Fredeen, A. L., G. W. Koch, and C. B. Field, Influence of fertilization and atmospheric CO₂ enrichment on ecosystem CO₂ and H₂O exchanges in single- and multiple-species grassland microcosms, Environ. Experiment. Bot. 40, 147-157, 1998.
- 1391 Fung, I., C. B. Field, J. A. Berry, M. V. Thompson, C. M. Malmström, P. M. Vitousek, G. J. Collatz, P. J. Sellers, D. A. Randall, A. S. Denning, F. Badeck, and J. John, Carbon-13 exchanges between the atmosphere and the biosphere, Global Biogeochem. Cycles 11, 507-533, 1997.
- 1381 Gonzalez-Meler, M. A., L. Giles, M. Ribas-Carbo, and J. N. Siedow, Is increased partitioning to the alternative oxidase a mechanism by which plants respond to low temperatures?, in Plant Mitochondria: From Gene to Function, I. M. Moller, P. Gardestrom, K. Glimelius, and E. Glaser, eds., pp. 31-35, Backhuys Publishers, Leiden, Netherlands, 1998.
- 1371 Grossman, A. R., and D. M. Kehoe, Transformation of the filamentous cyanobacterium Fremyella diplosiphon, in In Electrotransformation of Bacteria, N. Eynard and J. Teissie, eds., Springer-Verlag, Berlin, in press.
- 1396 Grossman, A. R., R. Schwarz, D. Bhaya, and N. Dolganov, Phycobilisome degradation and responses of cyanobacteria to nutrient limitation and high light, in Proceedings of the XI International Congress on Photosynthesis, G. Garab and J. Puszati, eds., Kluwer Academic Publishers, 1998.
- 1388 Grossman, A. R., The need for molecular technologies to address biological processes in the algae: the use of transformation for studies of the diatom cell surface, J. Phycol., in press.
- 1367 Huala, E., P. W. Oeller, E. Liscum, I.-S. Han, E. Larsen, and W. R. Briggs, Arabidopsis NPH1: a protein kinase with a putative redox-sensing domain, Science 278, 2120-2123, 1997.
- 1285 Hungate, B. A., F. S. Chapin, III, H. L. Pearson, and C. P. Lund, Elevated CO_2 and nutrient addition alter soil N cycling and N trace gas fluxes with early season wet-up in California annual grassland, *Biogeochemistry* 37, 89-109, 1997.
- 1395 Hungate, B. A., F. S. Chapin, III, H. L. Zhong, E. A. Holland, and C. B. Field, Stimulation of grassland nitrogen cycling under carbon dioxide enrichment, Oecologia 109, 149-153, 1997.
- 1407 Jones, R. L., C. R. Somerville, and V. Walbot, Annual Review of Plant Physiology and Plant Molecular Biology, Vol. 49, Annual Reviews, Inc., Palo Alto, CA, 1998.
- 1329 Kehoe, D. M., and A. R. Grossman, Using molecular genetics to investigate complementary chromatic adaptation: advances in transformation and complementation, Meth. Enzymol. 297, 279-290, 1997.
- 1400 Kehoe, D. M., P. Villand, and S. Somerville, DNA microarrays for studies of photosynthetic organisms, Trends Plant Sci. 4, 38-41.

- 1311 Luo, Y., J.-L. Chen, J. F. Reynolds, C. B. Field, and H. A. Mooney, Disproportional increases in photosynthesis and plant biomass in a California grassland exposed to elevated CO₂: a simulation analysis, Functional Ecol. 11, 696-704,
- 1312 Luo, Y., C. B. Field, and H. A. Mooney, Adapting GEPSI (Generic Plant Simulator) for modeling studies in the Jasper Ridge CO₂ project, Ecol. Model. 94, 81-88, 1997.
- 1302 Malmström, C. M., and C. B. Field, Viralinduced differences in response of oat plants to elevated carbon dioxide, *Plant Cell Environ.* 20, 178-189, 1997.
- 1346 Niyogi, K. K., O. Björkman, and A. R. Grossman, The roles of specific xanthophylls in photoprotection, Proc. Natl. Acad. Sci. USA 94, 14162-14167, 1997.
- 1372 Niyogi, K. K., A. R. Grossman, and O. Björkman, Arabidopsis mutants define a central role for the xanthophyll cycle in the regulation of photosynthetic energy conversion, Plant Cell 10, 1121-1134, 1998.
- 1389 Pogson, B. J., K. K. Niyogi, O. Björkman, and D. DellaPenna, Altered xanthophyll compositions adversely affect chlorophyll accumulation and nonphotochemical quenching in Arabidopsis mutants, Proc. Natl. Acad. Sci. USA 95, 13324-13329, 1998.
- 1414 Rhee, S.Y., Somerville, C.R., Tetrad pollen formation in Arabidopsis quartet mutants is associated with persistence of pectic polysaccharides of the pollen mother cell. Plant J. 15, 79-88, 1998.
- 1373 Schwarz, R., and A. R. Grossman, A response regulator of cyanobacteria integrates diverse environmental signals and is critical for survival under extreme conditions, Proc. Natl. Acad. Sci. USA 95, 11008-11013, 1998.
- 1409 Shimogawara, K., S. Fujiwara, A. Grossman, and H. Usuda, High-efficiency transformation of Chlamydomonas reinhardtii by electroporation, Genetics 148, 1821-1828, 1998.
- 1408 Toole, C. M., T. L. Plank, A. R. Grossman, and L. K. Anderson, Bilin deletion and subunit stability in cyanobacterial light harvesting proteins, Molecular Microbiol., in press.
- 1387 Wilson, I., and S. Somerville, Isolation and characterization of disease resistant genes in Arabidopsis, in Plant Micro Interactions, Vol. 5, in press.
- 1327 Wykoff, D. D., J. P. Davies, and A. R. Grossman, The effects of phosphorus and sulfur deprivation on photosynthetic electron transport in Chlamydomonas reinhardtii, Plant Physiol. 117, 129-139, 1998.
- 1369 Zacherl, M., E. Huala, W. Rudiger, W. R. Briggs, and M. Aalomon, Isolation and characterization of cDNAs from oat encoding a serine/threonine kinase: an early component in signal transduction for phototropism (accession nos. AF033096 and AF033097), Plant Physiol. 116, 869, 1998.



THE DIRECTOR'S ESSAY:

Cyclopia: From Monsters to Mutants

THE PROGRESS MADE IN RECENT YEARS ON THE STUDY OF TERATOLOGY HAS BEEN SO MARKED THAT IT IS NOW POSSIBLE TO RECONSIDER THE WHOLE SUBJECT AND TO PLACE IT UPON A PERMANENT SCIENTIFIC BASIS. FOR THIS PROGRESS WE ARE INDEBTED ALMOST EXCLUSIVELY TO THE EXPERIMENTAL EMBRYOLOGISTS.

-F. P. MALL (1917), CIW PUBLICATION NO. 226, P. 5.

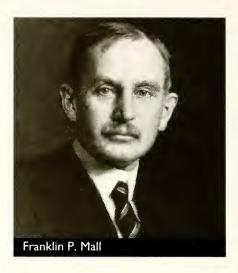
Humans have always been both fascinated and repelled by the occasional appearance of stillborn embryos with grotesque malformations. When the Department of Embryology was founded 84 years ago, such spontaneous "monsters" were recognized as rare resources where the effects of altered development could be studied in mammals. Among the most striking are "cyclopean" embryos, in which a single eye develops along the midline, as in the Cyclops of mythology. Partial or complete cyclopia is a relatively common developmental defect in humans, livestock, and many if not all other vertebrates. True cyclopia is now recognized as a particularly severe manifestation of a syndrome of related defects in craniofacial and brain development called "holoprosencephaly." In 1917, Franklin P. Mall, founder and first director of this department, summarized contemporary knowledge in his monograph "Cyclopia in the human embryo" (CIW publication no. 226). In attempting to explain the origin of cyclopean monsters, Mall grappled with issues central to the understanding of embryonic development. Many of these issues remain relevant today.

Mall's first conclusion, quoted above, is that virtually all progress in understanding developmental mechanisms comes from experimental studies on model organisms. In the case of cyclopia, the most informative studies carried out by 1917 were those on amphibian embryos by future Nobel prize winner Hans Spemann, and on fish embryos by C. R. Stockard at Woods Hole and Warren Lewis, a Department of Embryology staff member who made several landmark discoveries both before and after the department was founded. While Spemann used a fine hair to ligate embryos at a very early stage, forcing embryonic cells into two groups (each forming a separate, cyclopean head), Lewis's technique was far more precise. With the help of the low-power microscope, which he pioneered for embryological manipulation, Lewis was able to prick developing embryos at a specific site, thereby releasing and killing a small defined region. His treatments often produced cyclopia. The most astonishing results, however, were those of Stockard. When Stockard placed intact fish

Left: Production of a specific mutation in mice using embryonic stem cell technology. The father (dark with white spots) was generated by combining host albino embryos (white) with engineered donor embryonic stem cells (dark), which contained the desired mutation. When the father is mated to an albino mother, two kinds of offspring are produced whose coat color is determined solely by the genome of the father. In this case, the father is made of two types of cells, albino (normal) and dark (containing the mutation). His brown offspring will thus contain the desired mutation since they are derived from the genetically modified embryonic stem cells. (Generated by Noah May in the laboratory of Chen-Ming Fan; photographed by Kris Belchner.)

embryos in a magnesium chloride solution, more than half developed cyclopia. Studying the experimental manipulations that caused cyclopia seemed likely to provide deep insight into the mechanisms that regulate normal head and brain development.

In his monograph, Mall noted that regular rules governed the effects of experimental manipulations. Cyclopia could be induced only by treating very young embryos, before any visible evidence of eyes. Lewis found that pricking a precise location on the midline of the developing head region was effective; pricking just off the midline resulted in unilateral eye defects. Even the seemingly uniform effects of the magnesium bath were only manifest very early in embryonic development, and were most effective in embryos containing from just 8 to 32 apparently identical cells. Cell growth in general was retarded by the magnesium solution. Mall believed that specific groups of embryonic cells, including perhaps the same midline cells tar-



geted by Lewis, might be unusually sensitive to growth arrest at certain times and thus be particularly susceptible to damage.
Clearly, highly detailed events were taking place in early

embryos long before the appearance of recognizable adult structures. These events were specific to particular locations within the embryo and changed over time. Seemingly identical cells were already "fated" to produce particular body parts, so that interfering with a specific embryonic region at a particular time disrupted a predictable structure and process.

Embryology Beginnings

Embryology studies at the Carnegie Institution were formally initiated in 1914 by Franklin Paine Mall. Starting, literally, with a collection of human embryos, Mall established the Department of Embryology for innovative research in development. He and his staff cooperated with public health department physicians to procure hundreds of additional specimens. Artisans were employed to help with physical modeling and preservation of the collection.

Under the leadership of Mall and his successors, George Streeter and George Corner, the collection remained an integral part of the department until mid-century. At that time, James Ebert, the new director, began moving the department towards a genetics-based development program. In 1973, the embryo collection—consisting of 10,000 specimens—was sent to the University of California at Davis, where it was overseen by

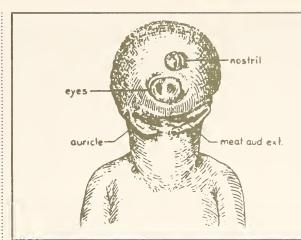


A normal embryo, number 417 from the Human Embryo Collection

Ronan O'Rahilly at the Carnegie Laboratories of Embryology. In 1991, the collection was donated to the National Museum of Health and Medicine of the Armed Forces Institute of Pathology in Washington, D.C., where, under the direction of Adrianne Noe, it is evolving into an on-line digital database.

What cells and processes might underlie the appearance of cyclopia? By 1917, embryologists had established that the eyes develop as outpocketings that originate just off the ventral midline of the embryonic brain. At these early stages the brain is no more than a simple "neural tube" underlain anteriorly by the prechordal plate and more posteriorly by the notochord, a transient rod of cells characteristic of the Chordate phylum that includes all vertebrates. Lewis's experiments suggested that the neural cells lying along the midline between two lateral eye primordia were the critical target for cylcopia induction. If these cells were lost, the normally separate primordia would fuse together and form a single median eye. The forebrain itself is reduced in cases of human cyclopia, but experimentally Lewis could produce cyclopia in fish with nearly normal brains, ruling out brain size per se as the cause. This analysis implied that the behavior of embryonic cells depended critically on the nature of their neighbors. In the presence of the midline tissue, both eye primordia generated complete and separate eye structures. When midline tissue failed to form or was destroyed early in development, however, eye-forming cells could reassess their surroundings and change their behavior to produce a single, well-proportioned eye, or partially fused "hourglass" eyes, regardless of the exact number and position of the surviving progenitor cells.

The full significance of this regulative ability, however, was not realized until later. The smoothly integrated tissues in cyclopic and partially fused eyes strongly imply that the progenitor cells differentiate in harmony with their neighbors, at least locally. Today we recognize that this could not occur without extensive communication via signals between developing cells. However, the true significance of intercellular signals only began to be appreciated in 1924, with the publication of embryological experiments by Hans Spemann. Earlier, Lewis had grafted a region from the frog embryo known as the dorsal lip of the blastopore to a different site in a host embryo of the same species. A large amount of neural tissue developed at the location of the graft, leading him to conclude that the growth rate of the transplanted dor-



A cyclopean "monster." Drawing of a cyclopean human embryo. The major structures of the face are identified. Note that the ears have moved toward the midline, and lie below the cyclopean eye. From G.L. Streeter (1922), Contributions to Embryology, Vol. 14, pp. 111-138, Carnegie Institution of Washington.



sal lip was greatly increased in the new location. By transplanting dorsal lip tissue to a different species of frog (one differing in pigmentation), however, Spemann discovered that the dorsal lip, at the appropriate time and location, actually functioned differently. A small amount of dorsal lip tissue induced nearby host tissues to take on completely new fates, forming a second embryonic

brain and axial structures. (Whether the extra neural material in Lewis's earlier experiments also derived from the host remains uncertain since graft and host tissue could not be distinguished.)



Embryo no. 559 from Mall (1917). The entire embryo is pictured in A, while B shows a histological section that reveals the partially fused cyclopean eye. (Photos courtesy of Elizabeth Lockett and Deborah Sweet, The National Museum of Health and Medicine, a division of the Armed Forces Institute of Pathology.)





In revealing the astonishing potency of embryonic signals, Spemann's experiment for decades remained the most famous in embryology. Today we know that embryonic cells send a wide array of signals at specific times and locations that keep development on course despite inevitable environmental perturbations and embryo-to-embryo variation. For cyclopia, the existence of widespread signaling during development implied that the critical midline tissue might not be made up of neural cells serving as a passive spacer. Instead, the underlying cells of the prechordal plate might actively signal the neural midline thereby causing eye-forming cells to develop in two separate groups.

Mall felt that the ready production of cyclopic embryos by environmental factors vitiated the need to search for a genetic cause of the spontaneous human cases of cyclopia he had characterized. Genetic knowledge in 1917 was still primitive, and since the cyclopic embryos they studied did not survive, most researchers could not understand

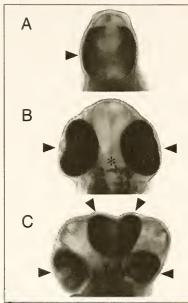
how a gene causing cyclopia could even be propagated. In fact, genetic studies would turn out to be the key to further progress in understanding the signals controlling the early differentiation of the vertebrate brain and eyes. Since each of the tens of thousands of genes in a vertebrate genome controls the production of a specific protein molecule, identifying the relative handful of genes that can cause cyclopia should reveal those few proteins that are critically important to the development and signaling of midline cells during eye development. To identify such genes, one needs organisms in which mutants can be readily induced, scored for their effects on embryos, propagated (as heterozygotes) in genetic stocks if they produce cyclopia, mapped to specific chromosomal sites, and molecularly cloned (based on their chromosomal position) to identify the nature of the encoded protein. It is only in recent times that a few model organisms have been developed to the point where each step in this long process has become routine.

YEAR BOOK 97-98

The first gene implicated in cyclopia, Sonic hedgehog (Shh), was characterized by former Embryology staff associate Phil Beachy shortly after he started his own lab at the Johns Hopkins University School of Medicine. Beachy initially cloned the Drosophila hedgehog gene, because in this genetically tractable organism hedgehog had been shown to send signals within the early embryo. He and other researchers subsequently found that the mouse and human genomes harbor three hedgehog-related genes, including Shh. Early in development, prechordal plate and notochord cells express high levels of the protein encoded by Shh. To investigate the protein's function, the scientists generated mice completely lacking a functional Shh gene. Shh-deficient mice did not come to term, but the embryos frequently developed cyclopia. These and other observations led to a model in which Shh signaling from the prechordal plate programs the differentiation of the overlying neural tube, and causes neural cells competent to form eyes to divide into two groups separated by midline cells. In the absence of the Shh signal, the cells fail to separate at all or remain too close together, leading to the production of a perfect or partial median eye, much as Mall proposed. It is now known that some human cases of holoprosencephaly are caused by the inheritance of defective Shh genes, as well.

The zebrafish is another vertebrate in which sophisticated genetic analysis is possible. This year, staff member Marnie Halpern, her colleagues Amy Rubinstein and Jennifer Liang, and their collaborator Chris Wright and his colleagues at Vanderbilt University and in Singapore, identified the molecular nature of the zebrafish cyclops gene, adding an important new piece to the puzzle of cyclopia. (Former Embryology staff member Igor Dawid and his colleagues at NIH also reported similar results.) Cyclops encodes a signaling molecule from the transforming growth factor beta family. Members of this family are potent regulators of growth and differentiation that act at many times during development, sometimes in conjunction with hedgehog family members. Halpern and colleagues found that events critical for eye separation actually begin much earlier than the postulated pre-

chordal plate signal, at a time when cyclops is strongly expressed, and while the embryo is still in the process of separating into individual layers, before a neural tube, prechordal plate, or notochord have even formed. Most likely, cyclops mediates signals between the precursors of these cells, which are needed for the growth or maintenance of the ventral midline cells that will much later signal to divide the eye precursors. Disruption of these initial signals may explain why very young embryos were the most sensitive to the experimental induction of



Cyclopean zebrafish. Image shows the head region of zebrafish embryos expressing too little (A), normal (B), and too much (C) amounts of Cyclops protein. A fused cyclopean eye has formed in A, while two partially fused additional eyes have developed in C. Arrowheads indicate eyes.



cyclopia in the experiments summarized by Mall.

The Halpern group's research also has important implications for understanding more generally how the brain is patterned. Current thinking has focused extensively on the *Shb*-mediated signals



Marnie Halpern with some of her collaborators. Left to right: Chris Wright (U. Vanderbilt), Amy Rubinstein (Carnegie), Karuna Sampath (U. Singapore), Lila Solnica-Krezel (U. Vanderbilt), Halpern, and Vladimir Korzh (U. Singapore).



sent by the notochord to pattern the overlying neural tube posterior to the eye-forming region. However, the Carnegie group's study of cyclops reinforces previous evidence from the Halpern lab that instructive signals for brain patterning begin much earlier, and are already flowing between neural and notochord precursor cells. The orderly formation of the immensely complex tissues and organs of the adult organism likely require a continuous sequence of such signals, only a small minority of which are currently known. Cyclops appears to function at multiple points. For example, after eye specification, cyclops protein accumulates to very different levels on the left and right sides of the brain, suggesting that it also mediates differences between left and right brain development.

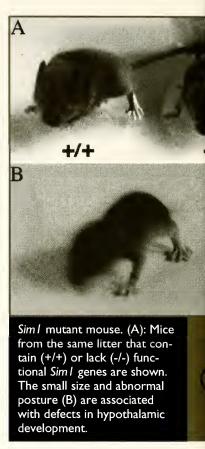
The continued importance of signaling along the midline for proper neural development is further supported by research carried out by staff member Chen-Ming Fan and his colleagues Jacques



Michaud and Noah May, and collaborator Thomas Rosenquist (SUNY, Stony Brook). Fan's group is analyzing the role played by two mouse genes, Sim1 and Sim2, that are expressed in precise regions of the developing mouse brain, including the hypothalamus, a key mid-

line structure that is often absent in cyclopia. As with Shh, interest in the Sim genes originated with a Drosophila homologue, "single-minded (sim)." The absence of Sim protein causes Drosophila brains to lose a key subpopulation of midline cells that are required to form the major neural connections between the left and right sides of the brain. By generating a mouse strain that lacks a functional Sim1, Fan's group demonstrated that Sim1 is essential for the development of a critical subgroup of neural cells located in three regions of the hypothalamus. Normally, based on information collected by the brain, the hypothalamus coordinates the activity of various body tissues by controlling the secretion of peptide hormones from the pituitary gland. A least five types of secretory neurons,

including those expressing the hormones oxytocin, vasopressin, thyrotropin-releasing hormone, corticotropin-releasing hormone, and somatostatin, are absent in the Sim1 mutant. Fan's group showed that Sim1 acts quite late during the differentiation of the critical neurons. Without these important hormones, mice lacking Sim1 die shortly after birth.



This work is impor-

tant not only in defining the genetic control of hypothalamic development, but in elucidating new general mechanisms that control neural differentiation. Sim1 is a member of the PAS-domain family of proteins, which are structurally related regulators of gene transcription and include genes that control circadian rhythms. The activity of at least one family member, the dioxin receptor, can be regulated in laboratory experiments by a small molecule, much like a hormone receptor. At present, however, very little is known about molecules that interact with PAS-domain proteins during normal development. Fan has postulated that ligands exist for other PAS-family members, including the Sim genes. Thus, further study of how Sim1 controls hypothalamic development may reveal the existence and mode of action of a new class of developmental hormones.

Hormonal effects on development have long been a topic for study in the department. (In fact, progesterone was discovered by former Embryology director George Corner.) Given our long familiarity with hormones, however, we know surprisingly little about the molecular mechanisms by which they work. We do know that when developing cells receive a hormonal signal, they respond ini-

YEAR BOOK *97–98*

tially by altering the pattern of genes they express. But exactly which genes are affected? Donald Brown's group has approached this question by studying how *Xenopus* tadpoles respond to the thyroid gland hormone thyroxin, which controls their metamorphosis into frogs. (In mice, the thyroid-stimulating hormone thyrotropin is one of the pituitary hormones whose production depends on *Sim1* function.) Using a powerful, general method they developed to answer such questions, Brown's group has now extensively characterized more than 30 specific genes that are turned either on or off following the release of thyroxin.

The biggest problem Brown faces is to learn the function of each specific change in gene activity. The critical experiment would be to observe the process of metamorphosis in 30 strains of frogs that each lacked one of the responding genes. Unlike zebrafish or mice, however, this type of experiment is impractical in Xenopus due to the frog's two-year generation time. Can we afford to limit the detailed analysis of gene function to only a handful of model organisms? Brown thinks not. He and his colleagues, Nick Marsh-Armstrong, Haochu Huang, and Ben Remo, are using an approach they have dubbed "F0 genetics" to circumvent the problem. In this approach, they inject specially designed genes into Xenopus sperm or newly fertilized eggs. The added gene produces a protein that interferes with the activity of one of the metamorphosis genes they wish to study. A great advantage of the technique is speed and simplicity. The consequences of disrupting the target gene are observed as soon as the injected and fertilized eggs grow into tadpoles and attempt metamorphosis. In contrast, a classical genetic approach would require multiple generations before function could be tested. However, the current F0 approach also has several disadvantages. Genes that interfere with a specific target gene cannot always be constructed, and not all the cells express the introduced gene uniformly. Nevertheless, Brown's group has already used the method to interfere with the function of thyroid hormone in vivo, and to rule out a postulated role for growth hormone in metamorphosis.

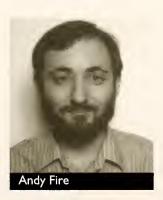
Recent work by staff member Andy Fire and his colleagues Sequin Xu, Mary Montgomery, and

Steve Kostas, with collaborator Craig Mello (University of Massachusetts) and his colleagues has the potential to greatly expand the scope and power of F0 genetics. Using the nematode *C*. elegans, Fire and his colleagues discovered a new way to potently and specifically inhibit gene expression in a single generation. Their approach, which is called "RNA interference," or "RNAi," appears to be effective with a large number of genes, and seems likely to function in other organisms as well. To carry out RNA inter-



ference, the researchers simply inject into the worms (or feed them) a small segment of double-stranded RNA corresponding in sequence to part of the target gene they wish to inhibit. As a result, the activity of the targeted gene declines drastically in the animals and their progeny. The use of RNAi can potentially save so much time compared to conventional genetics that it has already been widely adopted for experiments utilizing *C. elegans*, where extensive genetic technology is already available. The potential of the method in organisms that lack conventional genetics, such as *Xenopus*, is enormous.

A better understanding of how the injected RNA



interferes with gene expression will be required to fully realize that potential, however. The method almost certainly does not mutate the gene itself, since the inhibition is not permanent. Mature messenger RNA is thought to be the ultimate target,

because gene regions that are spliced out as the gene transcript is processed are completely ineffective. One exciting explanation is that worms (and probably many other organisms) possess a previously unrecognized defense mechanism designed to inactivate gene transcripts that appear in double-stranded RNA form. (Normally, only messages belonging to a virus or invading parasite would be expected to appear as double-stranded RNA.) If true, the mechanism might be widespread, and allow RNA interference to be applied in a wide range of animals and plants. The Fire group and many others are attempting to extend the method, both in the worm and to other species, and to investigate its many biological and medical implications.

Clearly, studies of vertebrate embryology continue to thrive in the department more than 80 years after Mall's review. Moreover, the focus is still on questions that would be familiar to the workers of his day. Today, however, researchers need not wait for "monsters" to appear spontaneously. Molecular genetic methods provide the means to produce and study an almost unlimited number of embryos with specifically programmed developmental alterations tailored to any question of interest. Not surprisingly, by basing experiments on the solid function of specific genes and genetic pathways, the depth of our knowledge is increasing enormously. Perhaps, most exciting of all, is that we can begin to glimpse the methods of tomorrow which promise to expand the scope of our investigations beyond a few favorable laboratory organisms and into every corner of the biological world.

News of the Department

Two new staff associates were appointed during the year. Jimo Borjigin carries out research on the vertebrate brain that will help continue the traditions discussed in this essay. Her recent focus has been the pineal gland, the key center in the brain where circadian behavior is modulated. Erika Matunis studies *Drosophila* spermatogenesis. The generation of male gametes represents a fundamental biological process that is still not well





understood. Because sperm have very different functional requirements than eggs, they present opportunities to study a wide range of cellular mechanisms that are uniquely required for this process.

Our seminar program was highlighted by the twenty-first Annual Minisymposium, entitled "Genomic Instability." Nancy Craig (Johns Hopkins School of Medicine), Meng-Chao Yao (Fred Hutchinson Cancer Research Center), Andrew Murray (UCSF), Christoph Lengauer (Johns Hopkins School of Medicine), Stephen Warren (Emory University School of Medicine), and Leonard Guarente (MIT) presented one-hour talks.

Support of research in the department comes from a variety of sources besides the institution. Doug Koshland and I, and various members of our labs are employees of the Howard Hughes Medical Institute. Others are grateful recipients of individual grants from the National Institutes of Health, the John Merck Fund, the G. Harold & Leila Y. Mathers Charitable Foundation, the American Cancer Society, the Jane Coffin Childs Memorial Fund, the Damon Runyon-Walter Winchell Cancer Fund, the Pew Scholars Program, the Alfred P. Sloan Foundation, National Science Foundation, and the Arnold & Mabel Beckman Foundation. We remain indebted to the Lucille P. Markey Charitable Trust for its support.

—Allan Spradling

Research Staff Members

Donald D. Brown Chen-Ming Fan Andrew Z. Fire Joseph G. Gall Mamie Halpem Douglas E. Koshland Allan C. Spradling, Director Yixian Zheng

Staff Associates

Alejandro Sánchez Alvarado Susan Dymecki Pernille Rorth²

Postdoctoral Fellows and Associates

Michel Bellini, Camegie Fellow Brian Calvi, Fellow, Markey Charitable Trust Orna Cohen-Fix, NIH Fellow Biswajit Das, Mathers Chantable Foundation (Brown)3 Maggie de Cuevas, Howard Hughes Research Associate, NIH grant (Spradling) Daniela Drummond-Barbosa, NIH Fellow, Carnegie Fellow Steve Farber, NIH Fellow

Shannon Fisher, NIH Fellow David Furlow, Research Associate, Mathers Charitable Foundation, NIH grant (Brown)4 Nicole Greider, European Molecular Biology

Organization, Carnegie Fellows

Vincent Guacci, Carnegie Fellow, NIH grant (Koshland)

William Kelly, NIH Fellow, NIH grant (Fire) Linda Keyes, NIH grant (Spradling)⁴ Shika Laloraya, Howard Hughes Research Associate Brigitte Lavoie, Canadian Research Council⁶ Jennifer Liang, NIH Fellow, Markey Charitable Trust,

Mary Lilly, Comegie Fellow

Carnegie Fellow⁷

Kelly Liu, Fellow, Markey Chantable Trust, NIH Fellow, Camegie Fellow

Nick Marsh-Armstrong, NIH grant (Brown) Paul Megee, Cancer Research Fund of the Damon Runyon-Walter Winchell Foundation Fellow, Howard Hughes Research Associate Pamela Meluh, NIH grant (Koshland)? Liz Mendez, Camegie Fellow²

Timothy Mical, Camegie Fellow¹⁹

Jacques Michaud, Fellow, Medical Research Council

Mary Montgomery, NIH Fellow¹⁺

Phil Newmark, Cancer Research Fund of the Damon Runyon-Walter Winchell Foundation Fellow,

Melissa Pepling, Howard Hughes Research Associate Amy Rubinstein, Fellow, Markey Chantable Trust, NIH Fellow, Camegie Fellow Robert Skibbens, NIH Fellow, Carnegie Fellow¹² Lisa Timmons, NIH Fellow, Camegie Fellow

Zengfeng Wang, Howard Hughes Research Associate¹³

Christiane Wiese, Fellow, Markey Charitable Trust, American Cancer Society Fellow, Carnegie Fellow Andrew Wilde, Carnegie Fellow¹⁴

Kathleen Wilsbach, Research Associate, Markey Charitable Trust²

Zheng-an Wu, Research Associate, NIH grant (Gall) Ting Xie, Howard Hughes Research Associate

Predoctoral Fellows and Associates

Jennifer Abbott, Johns Hopkins University Deborah Berry, Johns Hopkins University Valarie Bertoglio, Johns Hopkins University Kim Del, Johns Hopkins University Horacio Frydman, Johns Hopkins University Kristine Funkhouser, Johns Hopkins University Ru Gunawardane, Johns Hopkins University Korie Handwerger, Johns Hopkins University Brian Harfe, Johns Hopkins University Jenny Hsieh, Johns Hopkins University Haochu Huang, Johns Hopkins University Steve Kostas, Johns Hopkins University Catherine Lee, Johns Hopkins University Sofia Lizarraga, Johns Hopkins University Scott Nowak, Johns Hopkins University Susan Parrish, Johns Hopkins University

Supporting Staff

Betty Addison, Laboratory Helper Kristin Belschner, Photographer (P.T.)/Amphibian Facility Technician (P.T.) Norris Bryant, Custodian¹⁵ Ellen Cammon, Laboratory Helper Patricia Cammon, Laboratory Helper Lisa Coles, Animal Care Technician¹⁶ Pat Englar, Director's Administrative Assistant Jamie Fleenor, Technician¹⁷ Stacey Hachenberg, Technician Amy Hennessey, Fish Facility Technician¹⁸ Linda Henry, Administrative Assistant¹⁵ Bruce Hodess, Animal Care Technician²⁰ Eileen Hogan, Senior Technician Mei Hsu, Technician²¹ Connie Jewell, Graphic Artist Glenese Johnson, Laboratory Helper Rejeanne Juste, Technician²² Susan Kern, Business Manager Bill Kupiec, Computer Systems Manager Tong Tong Liu, Technician Michelle Macurak, Technician Jia Jia Mai, Technician⁴ Ona Martin, Senior Technician Noah May, Technician Ronald Millar, Building Engineer Nicole Mozden, Technician Christine Murphy, Senior Technician Christine Norman, Howard Hughes Medical Institute Research Secretary Allison Pinder, Research Technician III

Earl Potts, Custodian Sheri Rakvin, Administrative Assistant²³ Benjamin Remo, Technician Michael Sepanski, Electron Microscopy Technician Loretta Steffy, Accounting Assistant Dianne Stewart, Research Technician III Allen Strause, Machinist24 James Thomas, Principal Animal Care Technician Joe Vokroy, Instrument Maker/Facilities Manager²⁵ John Watt, Librarian Lijun Zhang, Technician Sigun Xu, Technician²⁶

Visiting Investigators and Collaborators

Francesc Cebria, Universitat de Barcelona Igor Dawid, National Institutes of Health Stephen Ekker, University of Minnesota Richard Elinson, University of Toronto Phil Hieter, Johns Hopkins School of Medicine Robert K. Ho, Princeton University Michael Krause, National Institutes of Health William F. Marzluff, University of North Carolina, Chapel Hill Mary Mullins, University of Pennsylvania Karen Oogema, European Molecular Biology Lab, Heidelberg, Germany Robert E. Palazzo, University of Kansas Rafael Romero, Universitat de Barcelona Gerald M. Rubin, University of California, Berkeley Mitch Smith, University of Virginia Lila Solnica-Krezel, Vanderbilt University Ted Weinert, University of Arizona Christopher V. E. Wright, Vanderbilt University Medical School

²To June 30, 1998 ³From July 18, 1997 ⁴To December 31, 1997

From September 22, 1997

From January 8, 1998

⁷From October 1, 1997 ⁸To January 5, 1998 ⁹To January 10, 1998

¹⁰ From May 15, 1998

¹¹To May 31, 1998 ¹²From August 1, 1997 ¹³From March 1, 1998

¹⁴ From May 22, 1998

¹⁵ From July 1, 1997

¹⁶ To September 14, 1998 ¹⁷ From January 5, 1998

¹⁸ From October 20, 1997

 ¹⁹ From February 16, 1998
 20 From April 1, 1998
 21 From December 28, 1997

²² From January 20, 1998

²³ To February 7, 1998

²⁴ From January 26, 1998

²⁵ To January 31, 1998 ²⁶ To February 3, 1998

Updated through December 1, 1998

Abbott, J., W. F. Marzluff, and J. G. Gall, The stem loop binding protein (SLBPI) is present in coiled bodies of the *Xenopus* germinal vesicle, *Mol. Biol. Cell*, in press.

Bellini, M., and J. G. Gall, Coilin can form a complex with the U7 snRNP, *Mol. Biol. Cell 9*, 2987-3001, 1998.

Brown, D. D., The role of thyroid hormone in zebrafish and axolotl development, *Proc. Natl. Acad. Sci. USA 94*, 13011-13016, 1997.

Berry, D. L., R. A. Schwartzman, and D. D. Brown, The expression pattern of thyroid hormone response genes in the tadpole tail identifies multiple resorption programs, *Devel. Biol.*, in press.

Berry, D., C. Rose, B. Remo, and D. D. Brown, The expression pattern of thyroid hormone genes in remodeling tadpole tissue defines distinct growth and resorption gene expression programs, *Devel. Biol.* 203, 24-35, 1998.

Calvi, B., M. Lilly, and A. C. Spradling, Cell cycle control of chorion gene amplification, Genes Devel. 12, 734-744, 1998.

Calvi, B., and A. C. Spradling, Chorion gene amplification in *Drosophila*: a model for metazoan origins of DNA replication and S phase control, in *Genetic approaches to Eukaryotic Replication and Repair*, Paul Fisher, ed., Academic Press, New York, in press.

Cohen-Fix, O., and D. Koshland, The metaphase to anaphase transition: avoiding a mid-life crisis, *Curr. Opin. Cell Biol. 9*, 800-806, 1997.

Cohen-Fix, O., and D. Koshland, The anaphase inhibitor of S. cerevisiae, Pds I p, is a mitosis specific target of the DNA damage checkpoint pathway, *Proc. Natl. Acad. Sci. USA 94*, 14361-14366, 1997.

de Cuevas, M., M. Lilly, and A. C. Spradling, Formation and function of germ line cysts, *Ann. Rev. Genetics* 31, 405-28, 1997.

de Cuevas, M., and A. C. Spradling, Morphogenesis of the fusome and its implications for oocyte specification, *Devel. 125*, 2781-2789, 1998.

Fan, C.-M., C. S. Lee, and M. Tessier-Lavigne, A role for WNT proteins in induction of Dermomyotome, *Devel. Biol.* 198, 160-165, 1997.

Field, C. M., K. Oegema, Y. Zheng, T. Mitchison, and C. E. Walczak, Purification of cytoskeletal proteins using peptide antibodies, *Meth. Enzym. 298, Part B*, 525-541, 1998.

Fire, A., S. Xu, M. K. Montgomery, S. A. Kostas, S. E. Driver, and C. C. Mello, Potent and specific genetic interference by double stranded RNA in *C. elegans, Nature* 391, 806-811, 1998.

Gall, J. G., Spread preparation of *Xenopus* germinal vesicle contents, in *Cell Biology: A Laboratory Manual, Vol. 1*, D. L. Spector, R. D. Goldman, and L. A. Leinwand, eds., 52.1-52.4, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY, 1997.

Gall, J. G., In situ hybridization of DNA and nuclear RNA in tissue squashes using ³H-labeled probes, in *Cell Biology: A Laboratory Manual, Vol. 3*, D. L. Spector, R. D. Goldman, and L. A. Leinwand, eds., Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY, 114.1-114.11, 1997.

Gall, J. G., and C. Murphy, Assembly of lampbrush chromosomes from sperm chromatin, *Mol. Biol. Cell* 9, 733-747, 1998.

Harbinder, S., N. Tavemakis, L. Hemdon, M. Kinnell, S. Q. Xu, A. Fire, and M. Driscoll, Genetically targeted cell disruption in *Caenorhabditis elegans, Proc. Natl. Acad. Sci. USA 94*, 13128-13133, 1997.

Harfe, B., and A. Fire, Muscle and nerve-specific regulation of a novel NK-2 class homeodomain factor in *C. elegans, Devel.* 125, 421-429, 1998.

Harfe, B., C. Branda, M. Krause, M. Stem, and A. Fire, MyoD and the specification of muscle and non-muscle fates in postembryonic development of the *C. elegans* mesoderm, *Devel.* 125, 2479-2488, 1998.

Harfe, B., A. VazGomes, C. Kenyon, M. Krause, and A. Fire, Analysis of a *Caenorhabditis elegans* twist homolog identifies conserved and divergent aspects of mesodermal patterning, *Genes Devel.* 12, 2623-2635, 1998.

Kelly, W., and A. Fire, Chromatin silencing and the maintenance of a functional germline in *Caenorhabditis elegans*, *Devel.* 125, 2451-2456, 1998.

Martin, O., R. Gunawardane, A. Iwamatsu, and Y. Zheng, Xgrip I 09: a g-tubulin associated protein with an essential role in gTuRC assembly and centrosome function, *J. Cell Biol. 141*, 675-687, 1998.

Meluh, P., and D. Koshland, Insights into budding yeast centromere composition and assembly revealed by *in vivo* crosslinking, *Genes Devel.* 11, 3401-3412, 1997.

Meluh, P. B., P. Yang, L. Glowczewski, D. Koshland, and M. M. Smith, Cse4p is a component of the core centromere of *Saccharomyces* cerevisiae, *Cell* 98, 607-613, 1998.

Michaud, J. L., T. Rosenquist, N. R. May, and C.-M. Fan, Development of neuroendocrine lineages requires the bHLH-PAS transcription factor SIM1, *Genes Devel.* 12, 3264-3275, 1998.

Miller-Bertoglio, V., S. Fisher, A. Sánchez, M. C. Mullins, and M. E. Halpem, Differential regulation of chordin: expression domains in mutant zebrafish, *Devel. Biol.* 192, 537-550, 1997.

Montgomery, M., and A. Fire, Double-stranded RNA as a mediator in sequence-specific genetic silencing and co-suppression, *Trends Genet.* 14, 255-258, 1998.

Montgomery, M. K., S. Xu, and A. Fire, RNA as a target for RNAi in *Caenorhabditis elegans*, *Proc. Natl. Acad. Sci. USA*, in press.

Moritz, M., Y. Zheng, B. M. Alberts, and K. Oegema, Recruitment of the gamma tubulin ring complex to *Drosophila* salt-stripped centrosome scaffolds, *J. Cell Biol.* 142, 775-786, 1998.

Newmark, P. A., and A. Sánchez Alvarado, Planarian regeneration, in *Encyclopedia of Life Sciences*, Macmillan Reference Ltd., London, England, in press.

Okkema, P. G., E. Ha., C. Haun, W. Chen, and A. Fire, The *C. elegans* NK-2 homeobox gene activates pharyngeal muscle gene expression in combination with pha-1 and is required for normal pharyngeal development, *Devel. 124*, 3965-3973, 1997.

Pepling, M., and A. C. Spradling, Female mouse germ cells form synchronously dividing cysts, Devel. 125, 3323-3328, 1998.

Sampath, K., A. L. Rubinstein, A. M. S. Cheng, J. O. Liang, K. Fekany, L. Solnica-Krezel, V. Korzh, M. E. Halpern, and C. V. E. Wright, Induction of the zebrafish ventral brain and floor plate requires cyclops/nodal signaling, *Nature* 395, 185-189, 1998.

Sánchez Alvarado, A., and P. A. Newmark, The use of planarians to dissect the molecular basis of metazoan regeneration, *Wound Repair and Regeneration* 6, 413-420, 1998.

Skibbens, R. V., L. B. Corson, D. Koshland, and P. Hieter, Ctf7p is essential for sister chromatid and links mitotic chromosome structure to the DNA replication machinery, *Genes Devel.*, in press.

Spradling, A. C., M. de Cuevas, D. Drummond-Barbosa, L. Keyes, M. Lilly, M. Pepling, and T. Xie, The *Drosophila* germarium: stem cells, germ line cysts and oocytes, Cold Spring Harbor Symp., *Quant. Biol. 62*, 25-34, 1997.

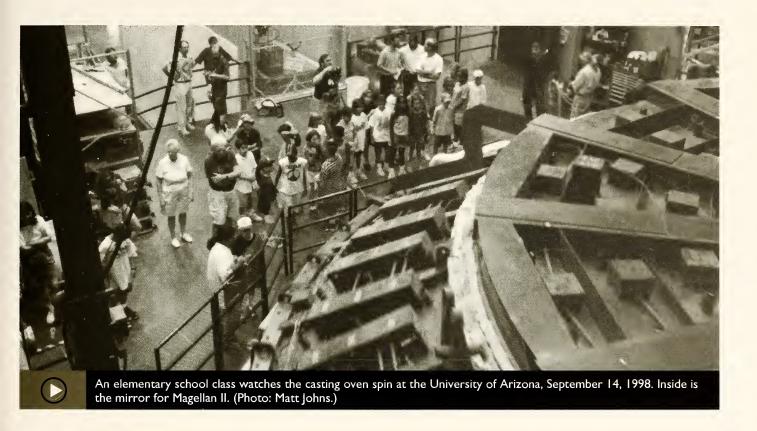
Timmons, L., and A. Fire, Specific interference by ingested dsRNA, *Nature* 395, 854, 1998.

Xie, T., and A. C. Spradling, Decapentaplegic is essential of the maintenance and division of germline stem cells in the *Drosophila* ovary, *Cell* 94, 251-260, 1998.

Zheng, Y., M. L. Wong, B. Alberts, and T. Mitchison, Purification and assay of g-tubulin ring complex, *Meth. Enzym.* 298, *Part B*, 218-228, 1998.

THE DIRECTOR'S ESSAY:

The Unseen Universe



The universe of the traditional astronomer is a universe of stars. When we look out from Earth with our eyes, or photographic plates, or CCD detectors, we see only stars or objects—such as planets and gaseous nebulae—that are illuminated by stars. The tools of the optical astronomer are devices for collecting and analyzing starlight, and most of what we know about the universe comes from such analysis.

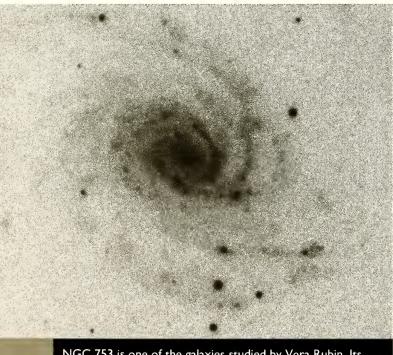
This is no accident. Our eyes evolved to detect radiation from the nearest star, and most other stars radiate in similar parts of the electromagnetic spectrum. Fortunately for astronomy, that radiation bears an enormous amount of information about the universe. The detailed spectral energy distribution of stellar or nebular light reveals the chemical composition, temperature, density, and velocity of the material that emits it, and of any non-luminous gas through which the light passes

on its way to our telescopes. Furthermore, its velocity is an indicator of the gravitational forces acting on the material, and therefore is a measure of the distribution of mass.

As astronomy progressed into the 20th century, the universe revealed by starlight seemed to be filled with the same matter, composed of the same elements, as that found on Earth, and most of that matter appeared to be in the form of stars. The mass of luminous and non-luminous gas seemed to be much less than that of stars, and the mass of solid matter—dust, planets, asteroids—seemed to be even less. The motions of stars and galaxies suggested that the mass in the universe was concentrated where the stars were, and in rough proportionality to their number. This conclusion was not only logical, it was comforting: since we could study only what we could see, it was convenient to be able to see most of what there was, especially if

stars and galaxies were composed of the same stuff as that found in earthly laboratories.

Unfortunately, the work of recent decades has overthrown that comforting picture. Astronomy has been forced to confront the possibility that most of the universe is unseen, and much of it indeed may be unseeable. Hints of this possibility were raised as early as the 1930s by Caltech astronomer Fritz Zwicky, but were generally ignored. Not until the 1970s, due in large part to the work of DTM astronomer Vera Rubin, did it become clear that the universe is dominated not by stars but by dark matter. By analyzing the rotational motions of spiral galaxies, Rubin showed that the distribution of mass in galaxies extends far



NGC 753 is one of the galaxies studied by Vera Rubin. Its rotational velocity is almost constant from the center to the outer edge, implying a mass distribution much more extended than that of the starlight.

beyond the stars themselves. In fact, stars contribute only a very small fraction to a galaxy's total mass. The situation in clusters of galaxies is even more extreme: most of the mass in clusters lies not in the galaxies at all, but smoothly distributed in the spaces between them.

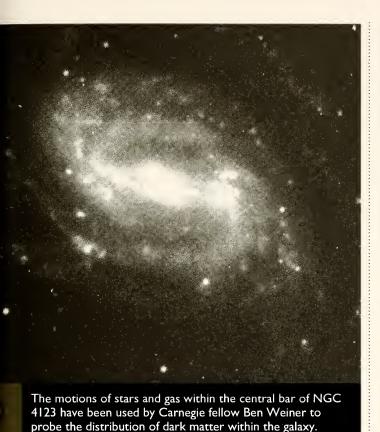
It gets worse. Various lines of argument suggest that most of the unseen matter in the universe cannot be the ordinary stuff of the periodic table—

baryons, in the language of physics—but must rather be some exotic form of non-baryonic matter. Observations at other wavelengths, x-rays in particular, show that most of the baryons are not in stars, but in hot, diffuse gas. Finally, recent work suggests that even a significant fraction of the stars themselves may lie hidden beneath the glow of the night sky, in very dim, diffuse systems. Thus, at the very end of the 20th century, one of the major tasks of astronomy is something that was thought completed half a century before: cataloging the contents of the universe.

Mapping Dark Matter

The relative distribution of baryons and dark matter, and the question of where and how baryons form visible stars, are among the most pressing issues in astronomy today. One clue is provided by the way stars and dark matter are distributed within galaxies. Models for the growth of structure in the universe make predictions about those distributions, but they are difficult to test. While Rubin showed that dark matter dominates the outer parts of galaxies, her observations were incapable of untangling the relative contributions of stellar and dark matter to the *cores* of galaxies, where both make up a significant part of the total mass.

Now, two elegant techniques pioneered by Observatories fellows are at last making galaxy cores more accessible for study. One approach targets the class of exceptionally dim, diffuse galaxies that are barely visible on the night sky—the verylow-surface-brightness galaxies. Because these galaxies have such a low density of stars, dark matter should dominate throughout, even in their centers. Rubin's technique to map the distribution of mass by measuring galaxy rotations is able to reveal directly the distribution of dark matter in these galaxies, from their centers to their peripheries. In an effort to test this hypothesis, Hubble fellows Julianne Dalcanton and Rebecca Bernstein are mid-way through a large project using that technique to map the distribution of stars and dark matter in 30 low-surface-brightness galaxies. In fact, the orbital velocities in many of the galaxies imply that the underlying dark matter fills a spher-



oid of almost constant density. Even though stars make a minor contribution to the total mass in those galaxies, Dalcanton and Bernstein find unusually tight relations between mass and stellar populations. These galaxies must be exceptionally pristine and undisturbed (such fragile objects could not survive much jostling) and may preserve fundamental relationships that have been erased in galaxies with more turbulent histories.

A complementary technique applicable to more common types of galaxies has been developed by Carnegie fellow Ben Weiner in collaboration with Jerry Sellwood and Ted Williams (Rutgers) and Jacqueline van Gorkem (Columbia). Although the majority of galaxies exhibit rotational symmetry, a significant fraction of spiral galaxies do not. These galaxies contain elongated structures, called bars, in their centers. The dynamics of such features are reasonably well understood, and it is clear that the bars are structures only of the stellar mass; the dark matter in these galaxies remains axisymmetrical. Weiner and his collaborators have been studying the motions of gas in the centers of several barred galaxies. The degree to which these motions are influenced by the bar is a measure of the degree to

which the stars, rather than the dark matter, dominate the mass distribution in the galaxies' centers. The observations indicate that, in contrast to what Dalcanton and Bernstein observed in low-surface-brightness galaxies, stars rather than dark matter dominate the central regions of barred galaxies.

The two results together support models in which a galaxy's structure and final destiny is determined by the mass and amount of spin of the initial protogalactic gas cloud. (As a protogalactic gas cloud collapses to form a galaxy, centrifugal force keeps the material in more rapidly spinning systems spread out over a greater area than it does in those systems with less rapid rotation; see Dalcanton's essay about low-surface-brightness galaxies in Year Book 95, p. 31.) Eventually, both observational programs should help astronomers determine the size of dark matter halos as a function of galaxy properties. This knowledge is critical for understanding galaxy formation.

Clusters of Galaxies

Although our understanding of the distribution of stars and dark matter within galaxies is still imper-



A supergiant cD galaxy dominates the center of the cluster Abell 2218. Its luminous envelope extends well beyond the edge of this photograph.



fect, it is far more complete than what we know about the environment outside of galaxies. In addition to the starlight observed in individual galaxies, we know that a significant amount of starlight hides within clusters of galaxies. Many rich clusters are dominated by central cD galaxies, which are supergiant ellipticals surrounded by enormously extended envelopes of stars. The great extent and total luminosities of these envelopes are often greater than that of all the other galaxies in the cluster, suggesting that they belong as much to the cluster as they do to the central galaxy.

The origin of this sea of stars is poorly understood. As far as we know, all stars are born in galaxies. Thus, if the stars in a cD envelope are bound to the central galaxy, they were most likely born in that galaxy. Alternatively, if the stars are bound instead to the cluster, they are much more likely to



Postdoctoral fellows, left to right: Ben Weiner, Scott Trager, Rebecca Bernstein.

be the remnants of disrupted galaxies, torn apart by encounters with other galaxies in the cluster. Early work by Alan Dressler in the 1980s indicated that the velocities of the stars in the very outer envelopes of cD galaxies are more similar to the velocities of stars in the outer galaxies than they are to cD galaxies in the center, supporting the latter idea—i.e., that the stars are remnants of disrupted galaxies. Now, Observatories fellows Scott Trager and John Mulchaey, DTM fellow Dan Kelson, and UC Santa Cruz astronomers Ann Zabludoff (a former Carnegie fellow) and Michael Bolte have used the Keck Telescope to confirm Dressler's finding. They have also measured the metal abundances of the envelope stars, an important indicator of the stars' origin. (The heavy elements, what astronomers call "metals," are all products of the life cycle of stars. The metal content is thus an indicator of the past history of stellar populations.) Trager, Mulchaey, and colleagues find that metal abundance falls as one moves outwards through a cD envelope, as is typical in the outer parts of galaxies (outer stars tend to be older and more metal poor). But then, in the very outer reaches of the envelope, the abundance rises again. This suggests the dominant presence in the outer envelope of a population of younger stars, perhaps those from disrupted galaxies that were once part of the cluster.

Another significant component of clusters is hot gas. This gas, spread throughout clusters at temperatures of millions of degrees, is seen only by its x-ray emission, and, until recently, was detectable only in dense clusters. Its total mass is as much as a factor of ten greater than the mass of all the stars, both those within the galaxies and those in any cD envelope. Recently, Mulchaey and his collaborators showed that hot gas is present in great quantities not only in populous clusters, but in groups of galaxies containing only a few dozen galaxies—groups that are a tenth the size of the typical cluster. This is most important. Clusters are exceptional environments and only a very small fraction of galaxies inhabit them; most galaxies are in small groups. Thus, if gas is the dominant component of the more common environment, it may be much more prevalent than astronomers had thought, perhaps adding appreciable amounts of baryonic mass to the universe. Even more recently, Mulchaey and Zabludoff found individual isolated elliptical galaxies that contain envelopes of hot gas as large as those associated with cD galaxies in groups. They speculate that these envelopes may

YEAR BOOK *97–98*

be remnants from former populations of smaller galaxies that were swallowed by the isolated ellipticals, leaving only the gaseous envelopes behind.

Clusters and groups of galaxies provide the starkest example of how much the contents of the universe differ from our naive conclusions of a half century ago. The galaxies by which we recognize and define a cluster represent an almost insignificant fraction of its contents. Most of a cluster's stars are not in galaxies but in a smooth surrounding sea; most of its baryons are not in stars but rather in a sea of gas, and most of its mass is not in baryons but rather in a sea of dark matter.

The Gas Content of the Universe

If the abundance of gas in clusters and populous groups is an indication of the general inefficiency with which the gas originally filling the universe was turned into galaxies, then large quantities of gas should lurk everywhere. In densely populated environments, gas is hot enough to be luminous in easily detectable x-rays. However, in less populous environments, the gas is presumably much cooler, less luminous, and therefore more difficult to detect. Much work has been devoted to searching for cool gas in nearby groups of galaxies, with little success. Now, astronomers are beginning to wonder if the long-sought gas might be right under our noses, in the Local Group of galaxies of which our own Galaxy is a part. In addition to the large and well-understood mass of gas which fills the Galactic disk, a number of gas clouds are observed whose velocities and positions are inconsistent with belonging to the disk. These "high-velocity clouds" have long been thought to be material falling back into the Galaxy after being ejected in supernova explosions. It has recently been suggested, however, that at least some of these clouds are not associated with our Galaxy at all but are more distant inhabitants of the Local Group.

Determining the distance to an object is one of the most fundamental, and maddeningly difficult, problems in astronomy. There is little to tell whether these high-velocity clouds are small and



nearby, attached to the Galaxy, or large and far away members of the Local Group. Weiner and Stuart Vogel (U. Maryland) have used the du Pont Telescope to make extremely sensitive searches for hydrogen emission from high-velocity clouds. If the clouds are nearby, they reason, then radiation from the Galactic disk should excite the gas within them and produce an observable amount of emission; if the clouds are far away, there should be little or no emission. The results suggest that the largest clouds, which show significant hydrogen emission, are attached to the Galaxy, but that some of the smaller clouds, which produce no emission, may be true intergalactic clouds.

A more powerful, but difficult to interpret, probe for intergalactic gas clouds is provided by spectroscopy of quasi-stellar objects, QSOs. The ultraviolet spectra of QSOs contain absorption lines from gas clouds scattered along their lines of sight. The nature of these intervening objects is complex, and uncertain. Some may be gas clouds within the QSOs' host galaxies, analogous to the large, high-velocity clouds attached to our Galaxy. Some may be intervening galaxies along the lines of sight. Others, particularly those producing the weakest

absorption lines, are thought to be intergalactic, primordial gas clouds, perhaps similar to the small, high-velocity clouds observed in the Local Group by Weiner and Vogel.

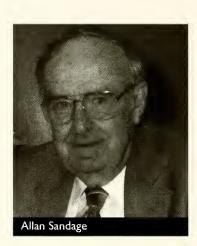
Recent theoretical models by several groups indicate that the distribution of gas in the universe is very complex. These models suggest that many of the gas clouds seen in QSO spectroscopy may not be actual physical clumps, but may instead represent "velocity caustics," in which gas, while spread out over vast distances, appears to pile up at certain velocities along the lines of sight. New research by Ray Weymann and Buell Jannuzi (KPNO) addresses this issue. They have completed their ultraviolet analysis of absorbers detected by the Hubble Space Telescope in the HST Quasar Absorption Line Key Project. These absorbers provide by far the best probe of gas distribution at low redshifts, i.e., at recent epochs. (The ultraviolet radiation of QSOs cannot penetrate the Earth's atmosphere and can only be observed from space with HST. From the ground, we can only observe very distant objects whose spectra have been redshifted into the visible.) Comparing the HST observations with ground-based observations, it is clear that the number of absorbers has plummeted with time, as structure in the universe evolved. However, Weymann and Jannuzi show that the abundance levels off at low redshifts (recent epochs), particularly in those producing the weakest absorption features. These results are very similar to those predicted by at least some of the velocity-caustic models, lending weight to this new interpretation of gas distribution.

Additional support for the new theoretical models may be found by testing the properties of some of the nearby absorbing systems. This can be done by locating galaxies in which individual absorption features are present. While past studies have successfully ascribed strong low-redshift features to particular galaxies, the real test is to do the same for the weakest low-redshift features. In collaboration with John Stocke, Michael Shull, and Kevin McLin (U. Colorado), Weymann has begun a survey with the du Pont Telescope to search for very

faint galaxies which may contain weak features. Failure to find them would lend strong support to the velocity-caustic models.

People

This year, like every year, saw the arrival of new people and the departure of others from the Observatories. Each coming and going makes a significant difference in the life of the department. This year, a milestone was passed of uncommon



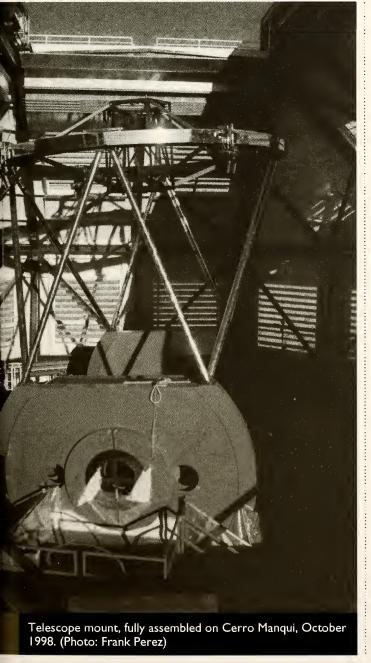
significance: the retirement of Allan Sandage. Allan first arrived on Santa Barbara Street in 1949, as a new Caltech graduate student sent up to work with Edwin Hubble. He was appointed a staff member in 1952, even before he received his Ph.D,

and, except for brief visits elsewhere, he has been here ever since.

The history of astronomy in the first half of the 20th century was written by a handful of people, many of whom worked at Carnegie's Mount Wilson Observatory. The history of the second half of the century has been the work of a multitude, but if one name stands out from the rest, it is that of Allan Sandage. The range of subjects to which Allan has made major contributions is immense: globular clusters, the structure and evolution of stars, galaxy classification, galaxy formation, Galactic structure, radio galaxies, quasars, and x-ray sources, in addition to his 50-year pursuit of the fundamental cosmological parameters.

Allan has received virtually every honor awarded to astronomers. His single-minded pursuit of understanding the universe has had a profound influence on several generations of astronomers. Astronomy is unlikely to see again anyone with his breadth and depth of influence. Happily for us, Allan's retirement was a mere formality and has not





diminished at all his presence on Santa Barbara Street. We hope that he will continue to be an active colleague for many years to come.

Magellan

This past year saw the long-awaited signing of the formal Magellan agreement between Carnegie and its partners: Harvard, MIT, and the Universities of Arizona and Michigan. The Magellan Council and Science Advisory Committee, with representatives from all five institutions, have begun their work of guiding the project. The Magellan I telescope now stands fully assembled in its enclosure on Cerro Manqui. Contracts have been let for the construction of the Magellan II telescope mount and enclosure. By mid-1998, polishing of the Magellan I primary mirror was nearing completion at the Steward Observatory Mirror Lab in Tucson, as was the assembly of the mold for the Magellan II primary. The f/11 secondary was nearing completion at Contraves, while work on the f/15 silicon carbine secondary was progressing slowly at Vavilov State Optical Institute in St. Petersburg.



YEAR BOOK 97-98



As first light for Magellan I approaches, work on Magellan instrumentation continues to accelerate. Considerable progress was made during the year on all three large instruments being constructed by Carnegie astronomers and technicians, though none has yet reached the stage of mechanical fab-

rication. The IMACS (Inamori Magellan Areal Camera and Spectrograph) team now consists of Alan Dressler, Bruce Bigelow, Brian Sutin, and Tim Bond. The optical design is complete, and glass has been ordered for the field lens, collimator, and both cameras. The preliminary mechanical design is expected to converge to a final design by early 1999.

Work on the DDI infrared camera and spectrograph, under the direction of Eric Persson and David Murphy, proceeds in parallel with work on a new infrared camera for the du Pont Telescope, being built in collaboration with Cambridge University. The latter camera, which contains an array of four 1024-square Rockwell detectors, will be an exceptionally powerful survey instrument. Much of the technology being developed for DDI, in fact, is finding a first application in this camera, which is expected to be completed in early 1999.

The Kyocera Echelle spectrograph, under the direction of Steve Shectman and Hubble fellow Rebecca Bernstein, is progressing at a similar rate. The optical design has been completed and the glass ordered, but the mechanical design is not yet finished. Consideration is now being given to adding a multi-object, optical fiber feed to the Echelle. When located at the 30-arc-minute-field Naysmith focus of Magellan, such an instrument would be enormously productive for many projects.

-Augustus Oemler, Jr.

Research Staff Members

uly 1, 1997 - June 30, 1998

Horace Babcock, Director Emeritus
Alan Dressler
Wendy Freedman
Patrick McCarthy
Andrew McWilliam
Augustus Oemler, Jr., Director
Eric Persson
Allan Sandage, Emeritus Staff Member
Leonard Searle, Director Emeritus
Stephen Shectman
Ian Thompson
Ray Weymann

Postdoctoral Fellows and Associates

Rebecca Bernstein, Hubble Fellow
Julianne Dalcanton, Fellow
Carme Gallart, Research Fellow
Mauro Giavalisco, Hubble Fellow
Lisa Storrie-Lombardi, Research Associate
Lori Lubin, Carnegie Fellow
Ron Marzke, Hubble Fellow
John Mulchaey, Fellow
Randy Phelps, Research Associate
Brian Rush, Research Associate
Scott Trager, Star Fellow
Ben Weiner, Carnegie Fellow
Lin Yan, Research Associate
Lin Yan

Predoctoral Fellow

Yasuhiro Hashimoto, Predoctoral Fellow

Las Campanas Research Staff

Patricia Knezek, Resident Scientist^a Wojciech Krzeminski, Resident Scientist^a William Kunkel, Resident Scientist Miguel Roth, Director, Las Campanas Observatory

Las Campanas Fellow

Gaspar Galaz, Andes/Camegie Fellow

Support Scientists

Bruce Bigelow, Instrument Scientist⁸ Greg Burley, Instrument Scientist⁹ David Murphy, Instrument Scientist Brian Sutin, Optical Scientist¹⁰

Supporting Staff, Pasadena

Joseph Asa, Magellan Electronics Technician Alan Bagish, Las Campanas Observatory Engineer Mohana Balachandran, Electrical Engineer Christoph Birk, Data Acquisition Programmer Richard Black, Grants, Human Resources and Purchasing

Greg Bredthauer, Magellan Project Support Engineer
David Carr, Magellan Project Instrument Engineer
Ken Clardy, Programmer
Paul Collison, Computer Systems Manager¹¹
Marinus de Jonge, Magellan Project
Construction Manager

Joan Gantz, Assistant Librarian

Darrell Gilliam, Electronic Technician 12 John Grula, Head Librarian, Information Services/Publications Manager¹³ Bronagh Glaser, Administrative Assistant Karen Gross, Assistant to the Director Earl Harris, Assistant, Building and Grounds Steve Hedberg, Accountant Charles Hull, Magellan Project Mechanical Engineer Matt Johns, Magellan Project Manager Imelda Kirby, Data Reduction Assistant Aurora Melia, Housekeeper Robert Mejia, Housekeeper Georgina Nichols, Controller Greg Ortiz, Assistant, Buildings and Grounds Stephen Padilla, Photographer Frank Perez, Magellan Project Lead Engineer Emily Petty, Magellan Project Administrative Assistant¹⁴

Olga Pevunova, Graduate Research Assistant¹⁵
Pilar Rameriz, Machine Shop Foreperson/Instrument
Maker
Scott Rubbl. Assistant Buildings and Grayands

Scott Rubel, Assistant, Buildings and Grounds Jeanette Stone, Purchasing Agent Robert Storts, Instrument Maker Estuardo Vasquez, Instrument Maker Steven Wilson, Faallities Manager

Supporting Staff, Las Campanas

Richard Alcayaga, Mechanic Carolina Algayaga, Administrative Assistant Victor Aguilera, Magellan Project Electronic Engineer Yerko Aviles, Administrative Assistant Hector Balbontin, Chef Pedro Carrizo, Plumber Emilo Cerda, Magellan Electronics Technician Oscar Cerda, Janitor Angel Cortes, Accountant Jose Cortes, Janitor Jorge Guadra, Mechanic Assistant Oscar Duhald, Mechanical Technician Julio Egana, Painter Juan Espoz, Mechanic Luis Gallardo, El Pino Guard Juan Godoy, Chef Jaime Gomez, Accounting Assistant Danilo Gonzalez, El Pino Guard Javier Gutierrez, Heavy Equipment Operator Juan Jeraldo, Chef Leonel Lillo, Carpenter Juan Lopez, Magellan Project Supervisor Mario Mondaca, El Pino Guard Cesar Muena, Night Assistant Pascal Munoz, Cook Silvia Munoz, Business Manager Herman Olivares, Night Assistant Fernando Peralta, Night Assistant Leonardo Peralta, Driver/Purchaser¹⁶ Patricio Pinto, Electronics Technician Robert Ramos, Gardener Demesio Riguelme, Janitor Hugo Rivera, Night Assistant Honorio Rojas, Water Pump Operator Hernan Solis, Electronics Technician Gabriel Tolmo, El Pino Guard Manuel Traslavina, Heavy Equipment Operator David Trigo, Mountain Operation Supervisor Patricia Villar, Administrative Assistant

Visiting Investigators

Leonardo Bronfman, University of Chile Ray Carlberg, University of Toronto Richard Ellis, Cambridge University David Gibson, University of California Wolfgang Gieren, University of Concepcion John Graham, Department of Terrestrial Magnetism Leopoldo Infante, Catholic University of Chile Januz Kaluzny, Warsaw University Dan Kelson, Department of Terrestrial Magnetism Marcin Kubiak, Warsaw University Arlo Landold, Louisiana State University Barry Madore, Colifornia Institute of Technology Steve Majewski, University of Virginia Jose Maza, University of Chile Mario Mteo, University of Michigan Peter Nelson, University of Lancashire Grzegorz Pietrzynski, Warsaw University Mark Phillips, CTIO Grzegorz Pojmanski, Warsaw University Wojciech Pych, Warsaw University Hernan Quintana, Catholic University of Chile Dan Regan, Department of Terrestrial Magnetism Neill Reid, California Institute of Technology Monica Rubio, University of Chile François Schweizer, Department of Terrestrial Magnetism Mike Segal, University of Virginia lan Smail, University of Durham Michal Szymanski, Warsaw University Andrzej Udalski, Warsaw University

Dennis Zaritsky, University of California at Santa Cruz

*To December 31, 1997

*From August 20, 1997

*To August 31, 1997

*From January 15, 1998

*From October 1, 1997

*To July 31, 1997

*To July 31, 1997

*Retired February 28, 1998

Stuart Vogel, University of Maryland

Paul Weissman, Jet Propulsion Laboratory

Retired February 28, 1998 From July 1, 1997 From September 1, 1997 From May 1, 1998

From May 1, 1998 From April 1, 1998 From June 15, 1998

¹³ From July 7, 1997 ¹⁴ From November 11, 1997

¹⁵To July 11, 1997 ¹⁶To April 30, 1998 Athreya, R., V. K. Kapahi, P. J. McCarthy, and W. van Breugel, Large rotation measures in radio galaxies at z > 2, Astron. Astrophys. 329, 809 1998.

Athreya, R., P. McCarthy, V. Kapahi, and W. van Breugel, The power and redshift dependencies of radio source linear sizes from the complete MRC/1Jy survey, *Astrophys. J.*, in press.

Dalcanton, J. J., The overlooked galaxies, Sky & Telescope 95, 28, 1998.

Dalcanton, J. J., Systematic biases in galaxy luminosity functions, *Astrophys. J.* 495, 251, 1998.

Dinshaw, N., R. J. Weymann, C. D. Impey, C. B. Foltz, S. L. Morris, and T. Ake, Additional observations and analysis of the Lyman alpha absorption lines toward the QSO pair Q0107-25A,B, Astrophys. J. 491, 45, 1997.

Dinshaw, N., C. B. Foltz, C. D. Impey, and R. Weymann, Ultraviolet spectroscopy of the quasar pair LB9605, LB9612 with the *Hubble Space Telescope*: evolution in the size of the Lyman-alpha absorbers?, *Astrophys. J.* 494, 567, 1998

Dressler, A., A. Oemler, Jr., W. J. Couch, I. Smail, R. S. Ellis, A. Barger, H. Butcher, B. M. Poggianti, and R. M. Sharples, Evolution since z=0.5 of the morphology-density relation for clusters of galaxies, *Astrophys. J.* 490, 577, 1997.

Ellis, R. S., I. Smail, A. Dressler, W. J. Couch, A. Oemler, H. Butcher, and R. M. Sharples, The homogeneity of spheroidal populations in distant clusters, *Astrophys. J.* 483, 582, 1997.

Faber, S.M., S. Tremaine, S. Ajhar, Y. I. Byun, A. Dressler, K. Gebhardt, C. Grillmair, J. Kormendy, T. R. Lauer, and D. Richstone, The centers of early-type galaxies with HST. IV. Central parameter relations, *Astron. J.* 114, 1771, 1997.

Freedman, W. L., Determination of the Hubble constant, in *Critical Dialogs in Cosmology*, Princeton 250th Anniversary Conference, N. Turok, ed., pp. 92-129, World Scientific Press, 1996.

Freedman, W. L.,The expansion rate and size of the universe, *Scientific American Quarterly No. 1*, pp. 92-97, 1997.

Freedman, W. L., Measuring cosmological parameters, *Proc. Natl. Acad. Sci. USA 95*, 2-7, 1998.

Freedman, W. L., Measuring cosmological parameters, in *Eighteenth Texas Symposium on Relativistic Astrophysics and Cosmology*, A. V. Olinto, J. A. Frieman, and D. N. Schramm, eds. pp. 188-218, World Scientific Press, Singapore, 1997.

Freedman, W. L., B. F. Madore, and R. C. Kennicutt, The *Hubble Space Telescope* key project on the extragalactic distance scale, in *The Extragalactic Distance Scale*, M. Donahue

and M. Livio, eds., pp. 171-185, Space Telescope Science Institute Symposium Series 10, Cambridge University Press, Cambridge and New York, 1997.

Gallart, C., Observational discovery of the asymptotic giant branch bump in densely populated color-magnitude diagrams of galaxies and star clusters, *Astrophys. J. Lett.* 495, L43, 1997

Gallart, C., W. L. Freedman, M. Mateo, C. Chiosi, I. B. Thompson, A. Aparicio, G. Bertelli, P. W. Hodge, M. G. Lee, E. O. Olszewski, A. Saha, P. B. Stetson, and N. B. Suntzeff, HST observations of the local group dwarf galaxy Leo~l, Astrophys. J., in press.

Gizis, J. E. and I. N. Reid, Probing the LHS catalog: new nearby stars and the coolest subdwarf, *Publ. Astron. Soc. Pac. 109*, 849, 1997.

Harris, J., J. D. Zaritsky, and I. B. Thompson, On the distribution of dust in the Large Magellanic cloud, Astron. J. 114, 1933, 1997.

Hashimoto, Y., A. Oemler, H. Lin, and D. L. Tucker, The influence of environment on the star formation rates of galaxies, *Astrophys. J.* 499, 589, 1998.

Hill, R., W. L. Freedman et al., The Hubble Space Telescope extragalactic distance scale key project. V. Photometry of the brightest stars in M100 and the calibration of WFPC2, Astrophys. J. 496, 648-660, 1998.

Hughes, S., W. L. Freedman et al., The Hubble Space Telescope extragalactic distance scale key project. X. The Cepheid distance to NGC 7331, Astrophys. J. 501, 32-53, 1998.

Johansson, L. E. B., A. Greve, R. S. Booth, F. Boulanger, G. Garay, Th. De Graauw, F. P. Israel, M. L. Kutner, J. Lequeux, D. C. Murphy, L.-A. Nyman, and M. Rubio, Results of the SEST key programme: CO in the Magellanic clouds. VII. 30 Doradus and its southern H II regions, Astron. Astrophys. 331, 857, 1998.

Ishwara-Chandra, C. H., D. J. Saikia, V. K. Kapahi, and P. J. McCarthy, A polarization study of radio galaxies and quasars selected from the Molonglo complete sample, *Mon. Not. Roy. Astron. Soc.* 300, 2691 1998.

Kaluzny, J., W. Krzeminski, M. Mazur, A. Wysocka, and K. Stepien, CCD survey for short period variables and sdB/O stars in 47 Tuc, Acta Astron. 47, 249, 1997.

Kaluzny, J., W. Krzeminski, and M. Nalezyty, New variable stars in the globular cluster NGC 288, Astron. Astrophys. Suppl. 125, 337, 1997

Kaluzny, J., M. Kubiak, M. Szymanski, A. Udalski, W. Krzeminski, M. Mateo, and K. Z. Stanek, The Optical Gravitational Lensing experiment. Variable stars in globular clusters. IV. Fields 104A-E in 47 Tucanae, Astron. Astrophys. Suppl. 128, 19, 1998.

Kapahi, V.K., R. Athreya, C. R. Subrahmanya, J. Baker, R. Hunsteard, P. McCarthy, and W. van Breugel, The Molonglo reference catalog | Jy radio source survey | III: identification of a complete quasar sample, Astrophys. J. Suppl. | 118, 327, 1998.

Kapahi, V. K., R. Athreya, W. van Breugel, P. McCarthy, and C. R. Subrahmanya, The Molonglo reference catalog | Jy radio source survey II: radio structures of galaxy identifications, *Astrophys. J. Suppl. 118*, 275, 1998.

Kennicutt, R. C., W. L. Freedman et al., The Hubble Space Telescope key project on the extragalactic distance scale. XIII. The metallicity dependence of the Cepheid distance scale, Astrophys. J. 498, 181-194, 1998.

Kerber, F., M. Roth, A. Manchado, and H. Groebner, New evolved planetary nebulae in the Southern Hemisphere, *Astron. Astrophys. Suppl. 130*, 501, 1998.

Kimeswenger, S., M. Roth et al., Planetary nebulae with DENIS. Capabilities for imaging nebulae, Astron. Astrophys. 332, 300, 1998.

Lehnert, M., G. Miley, W. Sparks, P. McCarthy, S. Baum, J. Biretta, and D. Golombek, The 3CR HST snapshot survey: quasars, *Astrophys. J. Suppl.*, in press.

Madore, B. F. and W. L. Freedman, Hipparcos parallaxes and the Cepheid distance scale, *Astrophys. J.* 492, 110-115, 1997.

Madore, B.F., W. L. Freedman, and S. Sakai, Helium core flash at the tip of the red giant branch: a population II distance indicator, in *The Extragalactic Distance Scale*, M. Donahue and M. Livio, eds., pp. 239-253, Space Telescope Science Institute Symposium Series 10, Cambridge University Press, Cambridge and New York, 1997.

Madore, B. F. and W. L. Freedman, Calibration of the extragalactic distance scale, in *Stellar Astrophysics for Nearby Galaxies*, A. Aparicio, A. Herrero, and F. Sanchez, eds., pp. 263-349, Cambridge University Press, 1997.

Madore, B. F., W. L. Freedman et al., Distance to the Fornax cluster using the *Hubble Space Telescope*: implications for cosmology, *Nature* 395, 47, 1998.

Magorrian, J. S. Tremaine, D. Richstone, R. Bender, G. Bower, A. Dressler, S. M. Faber, K. Gebhardt, R. Green, C. Grillmair, J. Kormendy, and T. Lauer, The demography of massive dark objects in galaxy centers, *Astron. J.* 115, 22825, 1998.

Mandushev, G. I., G. B. Fahlman, H. B. Richer, and I. B Thompson, On the blue straggler population of the globular cluster M55, *Astron. J. 114*, 1060, 1997.

Martel, A., W. Sparks, F. Macchetto, S. Baum, J. Bireta, D. Golombek, P. J. McCarthy, S. de Koff, and G. Miley, Discovery of an optical synchrotron jet in 3C 15, Astrophys. J. 496, 203, 1998.

McCarthy, P., W. Freudling, L.Yan, R. Weymann et al., The NICMOS extragalactic grism parallel survey. I. Emission-line objects, Astrophys. J., in press.

McCarthy, P. J., G. Miley, S. de Koff, S. Baum, S. Sparks, D. Golombek, J. Biretta, and F. Macchetto, *Hubble Space Telescope* snapshot survey of 3 CR radio source counterparts. II: Radio galaxies with z > 0.5, *Astrophys. J. Suppl.* 112, 415, 1997.

McCarthy, P., G. K. Miley, R. Fosbury, B. Rush, H. Rottgering, L. Pentericci, S. E. Persson, and W. van Breugel, NICMOS and WFPC2 imaging of the distant radio galaxy MRC 0943-242: implications for the alignment effect, Astrophys. J., in press.

McWilliam, A., Barium abundances in extremely metal-poor stars, *Astron. J.* 115, 1640, 1998.

McWilliam, A., Chemical evolution in extremely metal-poor stars, *Highlights of Astronomy*, in press.

Mulchaey, J. S., and A. I. Zabludoff, The properties of poor groups of galaxies. II. X-ray and optical comparisons, *Astrophys. J.* 496, 73, 1998.

Pentericci, L., H. Roettgering, G. Miley, H. Spinrad, P. J. McCarthy, W. van Breugel, and F. Macchetto, HST images of the extremely clumpy radio galaxy 1138-262 at z=2.2, Astrophys. J. 504, 139, 1998.

Persi, P., M. Roth et al., The stellar population in the Chameleon I dark cloud, in *Star Formation with the Infrared Space Observatory (ISO)*, JoaoYun and Rene Liseau, eds., 1998.

Persi, P., M. Felli, P. Lagage, M. Roth, L. Testi, Sub-arcsec resolution infrared images of the star-forming region G 35.20-1.74, *Astron. Astrophys.* 327, 299, 1997.

Phelps, R. L., S. Sakai, W. L. Freedman et al., The Hubble Space Telescope extragalactic distance scale key project. IX. The discovery of Cepheids in NGC 2090, Astrophys. J. 500, 763-788, 1998.

Preston, G., and A. Landolt, CS 22966-043: a bright new field SX Phoenicis star similar to those in NGC 5053, Astron. J. 115, 2515, 1998.

Rawson, D., W. L. Freedman et al., The extragalactic distance scale key project. VIII. The discovery of Cepheids and a new distance to NGC 3621 using the *Hubble Space Telescope*, *Astrophys. J.* 490, 517-556, 1997.

Reid, I. N., S. R. Majewski, M. H. Siegel, and I. Thompson, Star counts and the Galactic Halo, in *The Galactic Halo*, D. Zaritsky, ed., p. 3, ASP Conf. Series 136, 1997.

Sandage, A., SN 1932 GAT: a supernova of unique class, in Festschrift for the 65th Birthday of Professor G. A. Tammann, L. Labhardt, B. Binggeli, and R. Buser, eds., p. 201, Inst. of Astron., Basel, Switzerland, 1998.

Sandage, A., A. Saha, G. A. Tammann, L. Labhardt, F. D. Macchetto, and N. Panagia, On the sensitivity of the Cepheid period-luminosity relation to variations of metallicity, *Astrophys. J.*, in press.

Sandage, A., Astronomical problems for the next three decades, Invited introductory lecture in *The Universe at Large: Key Problems in Astrophysics*, Tenerife Conference, March 1995, p. 1, Cambridge University Press, 1998.

Sandage, A., and G. A. Tammann, Confirmation of previous ground-based Cepheid P-L zero points using Hipparcos trigonometric parallaxes, MNRAS 292, L23, 1998.

Sandage, A., Beginnings of observational cosmology in Hubble's time: a historical overview, in *Workshop on the Hubble Deep Field*, M. Livio, ed., p. 1, Cambridge University Press, 1998.

Sandage, A., Bias properties of extragalactic indicators. VII. Correlation of absolute luminosity and rotational velocity for SC galaxies over the range of luminosity classes from I to III-IV, Astron. J., in press. Jan. 99 Vol. I 17:157-166.

Sandage, A., M. Federspiel, and G. A. Tammann, The Virgo cluster distance from 21 cm line widths, *Astrophys. J.* 485, 115, 1998.

Siegel, M. H., S. R. Majewski, I. N. Reid, I. Thompson, A. U. Landolt, and W. E. Kukel, A possible detection of the Sgr dSph at b=-40 deg., Bull. Am. Astron. Soc. 29, 1341, 1997.

Sirola, C., D. Turnshek, R. Weymann, E. Monier, S. Morris, M. Roth, W. Krzeminski, W. Kunkel, O. Duhalde, and S. Sheaffer, First results from the Las Campanas QSO brightness monitoring program, *Astrophys. J.* 495, 659, 1998.

Smecker-Hane, T., A. McWilliam, and R. Ibata, Chemical abundances in the Sagittarius dwarf galaxy, *Bull. Am. Astron. Soc.* 30, 916, 1998.

Spergel, D., M. Bolte, and W. L. Freedman, *The Age of the Universe*, Natl. Acad. Sci. Frontiers of Science, 1997.

Stanek, K. Z., D. Zaritsky, and J. Harris, A 'short' distance to the Large Magellanic cloud with the Hipparcos calibrated red clump stars, *Astrophys. J. Lett.* 500, 141, 1998.

Trager S. C., S. M. Faber, A. Dressler, and A. Oemler, Galaxies at $z\sim4$ and the formation of population II, *Astrophys. J.* 485, 299, 1997.

Testi, L., M. Felli, P. Persi, and M. Roth, H II and hot dust emission around young massive stars in G9.62+0.19, Astron. Astrophys. 329, 233, 1998.

Testi, L., M. Felli, P. Persi, and M. Roth, Near-infrared images of star-forming regions containing masers. Las Campanas observations of 31 southern sources, Astron. Astrophys. Suppl. 129, 495, 1998

Trager, S. C., G. Worthey, S. M. Faber, D. Burstein, and J. J. Gonzalez, Old stellar populations. VI. Absorption-line spectra of galaxy nuclei and globular clusters, *Astrophys. J. Suppl.* 116, 1, 1998.

Tucker, W., P. Blanco, S. Rappoport, L. David, D. Fabricant, E. E. Falco, W. Forman, A. Dressler, and M. Ramella, E0657-56: a contender for the hottest known cluster of galaxies, Astrophys. J. Lett. 496, L5, 1998.

Turner, S., W. L. Feedman et al., *The Hubble Space Telescope* extragalactic distance scale key project. XI. The Cepheids in NGC 4414, Astrophys. J. 505, 207-229, 1998.

Yan, L., P. J. McCarthy, L. Storrie-Lombardi, and R. Weymann, Deep H-band galaxy counts and half-light radii from *Hubble Space Telescope/NICMOS* parallel observations, *Astrophys. J. 503*, L19, 1998.

Yi, S., P. Demarque, and A. Oemler, On the origin of the ultraviolet upturn in elliptical galaxies. I. Sensitivity of UV population synthesis to various input parameters, Astrophys. J. 486, 201, 1997.

Yi, S., P. Demarque, and A. Oemler, On the origin of the ultraviolet upturn in elliptical galaxies. II. Test of the horizontal-branch hypothesis, *Astrophys. J. 492*, 480, 1998.

Zabludoff, A. I., and J. S. Mulchaey, The properties of poor groups of galaxies. I. Spectroscopic survey and results, *Astrophys. J.* 496, 39, 1998.

Zabludoff, A. I., and J. S. Mulchaey, Hierarchical evolution in poor groups of galaxies, *Astrophys. J. Lett.* 498, 5, 1997.

Zaritsky, D. and D. N. C. Lin, Evidence for an intervening stellar population toward the Large Magellanic cloud, *Astron. J.* 114, 2545, 1997.



THE DIRECTOR'S ESSAY:

The Stimulus of New Ideas and Enthusiasms

"...THE BASIS OF [POSTDOCTORAL] FELLOWSHIPS IS THE UNDOUBTED FACT
THAT THE STIMULUS OF NEW IDEAS AND ENTHUSIASMS, GROWING OUT OF THE
DIFFERENT BACKGROUNDS AND FRESH POINTS OF VIEW OF YOUNG
RESEARCH[ERS], IS MORE IMPORTANT TO OUR WORK THAN ANY OTHER FORM
OF SUPPORT."

MERLE A. TUVE (1939)*

The DTM postdoctoral fellowship program is an essential element of both the research and educational missions of the department. As former DTM staff member and director Merle Tuve noted sixty years ago, our postdoctoral scientists bring a vitality of new ideas and approaches that permeates all of our research activities. Our larger projects benefit from the involvement of multiple collaborators, including scientists at the postdoctoral level, who bring distinct technical or analytical skills to bear on critical questions. The department's investment in advanced instrumentation calls for a vigorous effort to ensure that such tools are effectively used to maximum scientific advantage, and a strong postdoctoral fellow program is the most promising means to achieve such a goal.

A multi-year tenure at the postdoctoral level is an increasingly important career stage in the education of a research scientist. At DTM, whether the individual's support is derived from the institution's endowment or from a federal grant, a hall-mark of the appointment is the independence afforded to pursue research in directions deemed by the individual to be of greatest promise and

importance. At the same time, there are ample opportunities to interact with senior staff, at the Geophysical Laboratory as well as DTM, who serve as mentors and potential collaborators. Both of these aspects of our program are highly valued by the postdoctoral scientists who have joined our ranks in recent years.

The DTM postdoctoral fellow program has its roots in the years immediately before World War II. The first postdoctoral scientist listed as a DTM fellow in the Year Book was Richard Roberts, appointed during 1937-1938 to work with the department's atomic physics group. (Roberts later joined the DTM staff and went on to a distinguished career in physics and biophysics; in 1981 a fund to support postdoctoral fellows was established in his honor.) Several additional fellows were appointed in the following two years, with the strong support of staff members such as Tuve. Following the war, Tuve (as DTM director) drafted a detailed outline of a postdoctoral fellowship program for the entire institution, and his plan became the basis for the modern practice.

^{*} Letter to DTM director John A. Fleming, 12 April 1939.

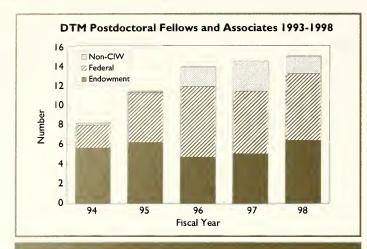


Fig. 1. Number of postdoctoral fellows and associates at DTM, expressed as person years for each of the last five fiscal years. Sources of support for fellows (Carnegie endowment or outside funds) and associates (federal grants) are indicated. Postdoctoral scientists with joint appointments at DTM and the Geophysical Laboratory are considered half time at DTM for the purposes of preparing this figure.

Over the last five years, considerable effort has been invested in the recruitment of postdoctoral scientists and in raising funds for their support. The number of postdoctoral scientists at DTM, expressed as fulltime person years, increased from 9 in 1993-1994 to 16 last year (Fig. 1). Several factors have enabled this increase. First, the staff has raised additional federal grant funds for the support of postdoctoral associates. Second, the department has partnered with the Geophysical Laboratory in an increasing number of joint appointments (there are presently five joint fellows). Finally, the department has benefited from the decision of several individuals who have won national fellowship competitions to carry out their fellowship research at DTM. (In residence at present are one Hubble Fellow and two NSF Earth Sciences Research Fellows.)

DTM postdoctoral fellows and associates last year contributed substantially to the research enterprise of the department. One simple statistical measure of the impact of their contributions is seen in the department's bibliography: of the 115 papers listed for the past year, 46% were authored or co-authored by present or recent DTM postdoctoral scientists. A richer demonstration of the impact of the postdoctoral program is provided by a look at some of the highlights from the past year of the research programs of individual fellows and associates.

Astronomy and Planetary Science

Research in astronomy and planetary science at DTM spans a broad intellectual reach, from the origin of the solar system to star formation in distant galaxies and galaxy dynamics. Our most recent group of postdoctoral scientists in this area has contributed substantively across the full spectrum of topics.

Theoretician Harri Vanhala employs numerical simulations to test hypotheses for the origin of the solar system. In particular, he is testing the triggered origin scenario, the suggestion that solar system formation occurred as a result of molecular cloud collapse initiated by a shock wave propagating from a nearby stellar source. This hypothesis can account for the presence of short-lived radioactive nuclides in meteorites as products of an explosive stellar event that were then transported to the solar system formation site by the shock wave. It is only in the last few years that computational capabilities have permitted numerical simulations at a resolution sufficient to test this idea. The simulations performed by Vanhala (Fig. 2) show that an

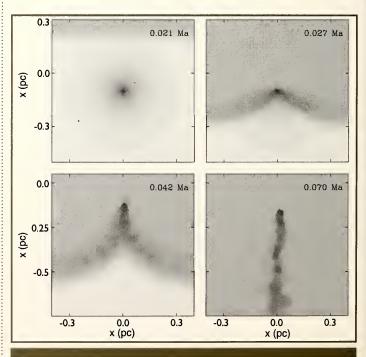


Fig. 2. Interaction between an interstellar shock wave and a molecular cloud core in a three-dimensional simulation by Harri Vanhala. The system is shown in the x,z-plane with the units in parsecs. The shock approaches from the +z direction with a velocity of 25 km s⁻¹. The times marked in the panels indicate the time from the initial approach in millions of years. The shading contours show the density in the system; the contours range from 10^{21} g cm⁻³ to 10^{14} g cm⁻³. The head of the filament in the last frame is collapsing, and the peak density is 1.7×10^{11} g cm⁻³, indicating that star formation will follow.

YEAR BOOK 97–98

interstellar shock wave can indeed initiate star formation, that material carried by the shock wave can be mixed into the forming system, and that the process is sufficiently rapid for short-lived radioactive nuclides to have survived in detected amounts. His results agree broadly with similar calculations performed earlier by Alan Boss's group with a different simulation method and different approximations. Ongoing work is aimed at the crucial question of understanding mixing in greater detail, and at the broader issue of whether the properties of planetary systems produced by triggered (or assisted) star formation differ from those created through unassisted star formation.

A somewhat later stage of the solar system formation process is the focus of work by fellow Kenneth Chick. Past computer simulations of gas disks around young solar-type stars have demonstrated the spontaneous, rapid formation of densi-

ty concentrations in the disk. These concentrations may represent the initial phase in the formation of gas-giant planets. Unfortunately, these simulations have relied on numerical techniques that can depict flow in the disk only over tens of years, a brief interval compared with the million-year lifetime of the disk. To determine whether early density concentrations eventually collapse into planets, Chick is working with Alan Boss to develop a disk-simulation code based on a fundamentally different type of numerical technique capable of following the evolution of gas flow over long timescales. A two-dimensional version of the code has been tested successfully against reference solutions with short time scales, such as the propagation of cylindrical sound waves, and further tests are under way for problems with longer time scales, such as the motion of slow tidal waves induced by an external force.



DTM staff on the front steps of the main building, Broad Branch Road campus, October 1998. First row (left to right): Sean Solomon, George Wetherill, Gregory Good, Vera Rubin. Second row: Stephen Shirey, John Lynch, Emilie Hooft, Laurie Benton. Third row: Lianxing Wen, Don Anderson, Janice Dunlap, John Almquist, Mary Horan, Mary Coder, Richard Bartholomew, Georg Bartels. Fourth row: Harri Vanhala, Wenjie Jiao, Richard Carlson, Shaun Hardy, Cecily Wolfe, Timothy Monk, Paul Silver, Kenneth Chick, Louis Brown, Thomas Aldrich. Fifth row: Michael Acierno, Daniela Power, Jane Goré, Teresia Nguuri, Nelson McWhorter, François Schweizer, Daniel Kelson, Brian Schleigh, Fouad Tera, Ben Pandit. Last row: Conel Alexander, Terry Stahl, David James, Randy Kuehnel, John Graham, Patrick McGovern, Alan Boss.



Postdoctoral associate Stephen Kortenkamp is exploring the implications for the growth of the inner planets of our solar system if the gas giants Jupiter and Saturn formed early. In current models for inner planet formation, approximately Marssize terrestrial planet "embryos" are formed by the accumulation of smaller planetesimals on a timescale of about 105 years. Conventional models for the formation of Jupiter and Saturn involve the accretion of a gaseous mantle onto a heavy-element core, a process expected to span a much longer time (about 10⁷ years) so that long-range gravitational perturbations would not inhibit the growth of terrestrial planets. Efforts to model the core-mantle formation of Jupiter and Saturn have not yet been successful, however. On the basis of his gaseous-disk calculations, Alan Boss has proposed that giant planets instead form by gravitational instabilities in the disk. Such an alternative model leads to formation times for Jupiter and Saturn of about 10⁵ years, nearly simultaneous with the formation of the Sun. Kortenkamp is working with George Wetherill on the question of whether long-range perturbations from earlyformed Jupiter and Saturn would preclude the formation of terrestrial planets and asteroids. He has found that, in the presence of gas in the protoplanetary disk, bodies with masses within a factor



Fig. 3. An image of the galaxy NGC 3351 (from Michael Regan) taken at a wavelength of 1.6 µm with the NICMOS camera on HST. While at this wavelength the images of most galaxies are dominated by older stars, in this galaxy the large amounts of dust and current star formation in the nuclear ring can be seen even at 1.6 µm. The rate of star formation in this ring is several times greater than in the entire Milky Way galaxy.

of about 10 of one another collide with sufficiently low encounter velocities to accumulate into larger bodies. At the Earth's distance from the young Sun, these bodies can continue to grow to the size of Mercury or Mars, and ultimately merge into an Earth-size planet. In contrast, in the asteroid belt the distance between the planetesimals and the giant planets is smaller, the perturbations are much stronger, and formation of planetary embryos is very unlikely unless the giant planets were initially considerably more distant, a result consistent with the absence of an object larger than the asteroids at that solar distance today.

Although recent observations suggest that massive black holes exist in the centers of most galaxies, not all galaxies display the large amounts of X-ray and ultraviolet emission associated with material falling into a black hole. Why is it that some galaxies exhibit this activity and some do not? One possibility is that some galaxies are better able to drive gas into their central regions. Gas is easily driven into the center of a galaxy if the stars, rather than being evenly distributed, are arranged in an oblong or bar. To look for these bars in active galaxies, Hubble fellow Michael Regan and Carnegie Observatories fellow John Mulchaey have undertaken a survey using the Hubble Space Telescope (HST) and a new HST instrument, the Near Infrared Camera and Multi-Object Spectrometer (NICMOS). By looking in the near infrared, one is better able to see the distribution of stars that are hidden by dust when observed at optical wavelengths (Fig. 3). Regan and Mulchaey's initial analysis of about 100 galaxies reveals no more bars in the active galaxies than in the normal galaxies. Their results lead to the conclusion that whatever determines why one galaxy is active and another is not is controlled very close to the black hole and not by the host galaxy.

Fellow Stacy McGaugh, now on the faculty of the University of Maryland, devoted his attention while at DTM to the measurement and interpretation of rotation curves for low-surface-brightness galaxies. The inference—made a number of years ago by Vera Rubin—that the rotation curves of galaxies cannot be explained on the basis of the mass of their visible portions led to the postulate that dark matter is a significant component of

matter in the universe. McGaugh has shown that the rotation curves of low-surface-brightness galaxies show severe mass discrepancies that extend from their centers, unlike high-surface-brightness galaxies where much of the inner rotation can be attributed to the luminous disk. The stars in these low-density galaxies act as accurate tracers of the potential of the hypothesized darkmatter halo, so such galaxies serve as laboratories for testing theories of galaxy formation.

Bryan Miller, a DTM postdoctoral associate with a joint appointment at the Space Telescope Science Institute (STScI) through the summer of last year and now at the University of Leiden, Netherlands, studied extragalactic star clusters as probes of galaxy evolution. Miller's observations with HST, carried out in collaboration with François Schweizer and Brad Whitmore (a former DTM fellow now at STScI), show that large numbers of star clusters display relatively young ages (inferred from spectral color) and likely formed during galaxy mergers. This finding supports the hypothesis, long championed by Schweizer, that elliptical galaxies can be formed by the merger of two spiral galaxies. Miller also began an HST project, with colleagues from STScI, to investigate star clusters in dwarf elliptical galaxies. The relatively large numbers of clusters he has found in dwarf ellipticals suggest that the merging of many such dwarf galaxies may be another way of building giant elliptical galaxies and their large star-cluster populations.

Observations of very distant galaxies provide an opportunity to learn about galaxies at a time when these objects were generally much younger than they are today. Barbara McClintock fellow Daniel Kelson is studying the evolution of galaxies in clusters to redshifts approximately equivalent to half the current age of the universe. For a typical population of stars, the total luminosity fades with time. However, when comparing the luminosities of different galaxies, one cannot know if one galaxy is brighter because it is younger or because it is more massive and simply contains more stars. This ambiguity can be removed by comparing the amount of light per unit mass, referred to as the light-to-mass ratio. A given galaxy's mass can be estimated by studying the random motions of its stars; the faster stars move within a galaxy's gravitational potential, the more massive the galaxy. For high-redshift (distant) galaxies, Kelson has been using HST to measure sizes and brightnesses and the Keck 10-m telescopes to measure internal motions. He has traced galaxy light-to-mass ratios for cluster galaxies as a function of redshift (time). On the basis of models that predict when such galaxies first experienced star-formation, he has shown that cluster galaxies are among the oldest objects in the universe, containing stars that formed when the universe was only a few billion years old. A long-term goal of his work is to understand why we see the myriad of galaxy shapes and morphologies that we do today.

Cosmochemistry and Geochemistry

The fields of cosmochemistry and geochemistry are often concerned with the elucidation of tracers of ancient events in the history of our planet or solar system. The tools of the trade are sophisticated instruments of high precision, and postdoctoral scientists at DTM made good use of those tools last year to report progress on a wide variety of problems.

Meteorites contain tiny dust grains whose extremely unusual isotopic compositions indicate that they condensed in ancient stars before the formation of our solar system. Detailed studies of these presolar grains have yielded a wealth of new information on galactic, stellar, and solar system astrophysics. However, since presolar grains are very rare in meteorites, investigations of many important questions have been hampered by poor statistics. To address this problem, fellow Larry Nittler developed an automated isotopic-ratio measurement system for use with the DTM ion microprobe. His system allows large numbers of micron-sized particles to be analyzed relatively quickly and rare types of presolar grains to be identified for further study. The first use of the new system to search for presolar oxide grains increased the total known set of these grains by ~20% in one week of mapping and resulted in the identification of a previously unrecognized presolar grain type (titanium oxide).

Fellow Richard Ash—a joint appointment of DTM, the Geophysical Laboratory, and the Smithsonian National Museum of Natural

History—employs oxygen isotopes to study the origin and early evolution of the solar system. Working with Conel Alexander and Douglas Rumble in the Geophysical Laboratory's ultraviolet laser fluorination facility, Ash can determine deviations in oxygen isotopic compositions from terrestrial values to the level of one part in 105, an order of magnitude better than conventional techniques, on samples as small as 500 µm in diameter. Ash and his colleagues have focused on chondrules, which are among the oldest solid materials formed in the solar system but whose origin and history remain enigmatic. Chondrules are silicate spheres, up to 5 mm in diameter, found within the most common class of meteorites and formed by the crystallization of a melt floating in free space. The group has shown that the primordial composition of most chondrules is dominated by characteristically nebular signatures, indicating that chondrules crystallized at conditions where isotopic fractionation effects were small. Chondrule formation must therefore have occurred while gas pressure in the primitive solar nebula was sufficiently high that gas-dust exchange dominated over simple evaporation.

Fellow Paul Tomascak, now at the Lamont-Doherty Earth Observatory, employs measurements of the isotopic composition of the element lithium (specifically the ⁷Li/⁶Li ratio) to probe both the early history of the solar system and more recent magmatic processes on Earth. One of the earliest users of DTM's new multi-collector inductively-coupled plasma mass spectrometer, Tomascak has shown that this instrument permits much more rapid measurements of 7Li/6Li than were possible with earlier methods. He has demonstrated that ⁷Li/⁶Li in early-formed meteoritic chondrules is similar to the ratio in terrestrial oceanic crust, a result indicating that the solar nebula ratio was established early in its evolution and was not later perturbed. Because the 7Li/6Li ratios of materials that have undergone chemical weathering near the Earth's surface are distinctly higher than mantle ratios, an important question is whether material subducted into the mantle retains this surficial lithium fingerprint. Tomascak's data from Hawaiian lavas imply that one component of the materials contributing magma at the Hawaiian hotspot preserves an isotopic memory of Earth surface processes.

NATO postdoctoral associate Harry Becker, now at the University of Maryland, examined the question of how plate subduction at deep-sea trenches may affect the fluxes of selected diagnostic elements into the mantle and the continental crust. So-called "incompatible" elements such as K, Rb, Ba, Sr, and U are depleted in the mantle and in fresh ocean-ridge basalts but become greatly enriched in young oceanic crust through reaction with seawater. These altered basalts, and their thin cover of oceanic sediments that also contain large quantities of these same elements, lose much of their water during the subduction of oceanic lithosphere into the hot mantle. The proportions of water and incompatible elements that are transferred from the subducted plate to the overlying mantle and that are subducted into the deep mantle, however, are not known. Exposed in continental crust are exhumed examples of ancient subduction zones, which include the high-pressure, metamorphosed equivalents of dehydrated subducted basalts. From chemical and isotopic measurements on such samples, Becker has shown that more than 90% of the K, Rb, and Ba contained in altered oceanic crust is lost during subduction at moderate to high temperatures, but that other elements are lost only to a moderate (e.g., U) or minor (e.g., Sr) extent. Becker's measurements provide a new basis to assess the mass balance of incompatible elements at island arc systems and the fluxes of such elements into the convecting mantle.

Volcanic rocks generated by partial melting of the mantle are a primary source of information on how the mantle has evolved. Postdoctoral associate and former NSF Earth Sciences Research Fellow John Lassiter has been pursuing the idea that isotopic variations in lavas from a single location may reflect small-scale heterogeneities in the mantle related to the presence of two distinct rock types that melt at different rates. While most of the upper mantle is made of peridotite, a small percentage of the mantle may consist of a different rock type called pyroxenite, which melts at lower temperatures. During melting events, veins of pyroxenite within the more abundant peridotite may be preferentially sampled because they melt to a greater extent. Pyroxenites are of interest because they may reflect ancient crust that has been recycled into the mantle or ancient melts that were

unable to escape to the surface but instead were "frozen" into the mantle. Because pyroxenites have much higher Re/Os ratios than peridotites, and because one of the isotopes of Re decays over time into a particular Os isotope, Os isotopes in mantle melts are sensitive to the presence of pyroxenites in the source rock. Lassiter found that the Os isotopes in Hawaiian lavas resemble values found in pyroxenite xenoliths from Hawaii but not those found in peridotites. He also demonstrated that the Os isotopes correlate with the bulk composition (e.g., aluminum content) of the lavas, indicating that the compositions of pyroxenite- and peridotite-derived melts are different. This information should enable the signature of pyroxenite melting in other settings to be discerned and ultimately the abundance and origin of pyroxenite in the upper mantle to be determined.

William Minarik, a joint fellow of DTM and the Geophysical Laboratory, has been exploiting the experimental resources of the two departments to understand the distribution of trace elements in the Earth's lower mantle. The most abundant mineral phases of the lower mantle are silicate perovskite and magnesiowüstite, composed primarily of the elements Si, Mg, Fe, Al, Ca, and O. During the formation of the Earth, a large portion of the mantle may have been molten, a consequence of the very large amounts of energy imparted to the Earth by the impacts of large (moon-sized to Mars-sized) bodies late in the history of inner

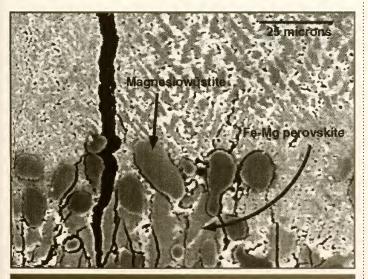


Fig. 4. Backscattered electron image of a polished sample in the high-pressure element-partitioning experiments of William Minarik, showing the interface between silicate melt (top) and the silicate minerals magnesiowüstite and perovskite.

planet accretion. As the magma "ocean" crystallized over a range of depths, all elements would have been variously partitioned between the crystallizing phases and the remaining melt. If we knew the partitioning behavior at lower mantle conditions, particularly for long-lived radioactive elements and their daughter product elements, then the concentrations and isotope ratios of elements in lavas erupted at the Earth's surface could be used to learn whether there are preserved minerals from the early magma ocean, whether there are lavas that formed in the lower mantle, or the extent to which ocean crust subducted into the deep mantle can be recycled and remelted to form new magma. Minarik grows minerals from melts at high pressures and temperatures in a hydraulic press in the laboratory of Yingwei Fei and measures the trace element concentrations in the tiny crystals, only 20-30 µm in size (Fig. 4), with the DTM ion microprobe, in collaboration with Erik Hauri. Minarik's measurements of the partitioning of 21 trace elements among perovskite, magnesiowüstite, and melt will be used by many geochemists trying to understand the evolution of the Earth's structure and composition over time.

Jie Li, the Grove Karl Gilbert fellow at DTM and the Geophysical Laboratory, has also been measuring the partitioning of elements at high pressures and temperatures, but with a different goal: understanding the composition of the Earth's core and the core-mantle differentiation process. On the basis of seismic velocities and density, the outer core is known to consist dominantly of liquid iron, but a significant fraction of lighter material is also required. To explore the nature of this light constituent, Li studied the partitioning of sulfur, oxygen, and silicon between liquid iron-nickel and liquid silicate at high pressures and temperatures. In collaboration with Carl Agee of NASA Johnson Space Center and colleagues at Harvard University, she has shown that sulfur is the dominant light element in the liquid iron-nickel alloy to the highest pressures of her experiments. In related work with the multi-anvil apparatus of Yingwei Fei at the Geophysical Laboratory, Li investigated the highpressure, high-temperature partitioning of sulfur and carbon between solid and liquid iron. Her initial findings suggest that sulfur may be a significant component of the Earth's solid inner core.

Geodynamics and Seismology

The Earth's internal dynamics, its seismic structure, and the nature of earthquakes and deformation along major fault zones are closely coupled topics. Postdoctoral scientists at DTM during the past year advanced our understanding of these fields on a number of fronts.

Dynamicist Carolina Lithgow-Bertelloni, an NSF Earth Sciences Research Fellow while at DTM and now on the faculty at the University of Michigan, together with Paul Silver, has produced an explanation for the long-standing mystery of the high elevation of the southern part of the African continent. The ancient and stable cores of continents, or cratons, generally stand about 400-500 m above sea level. The craton in southern Africa, however, stands as a plateau approximately 1200 m above sea level. Attempts by others to explain this anomaly by means of shallow processes, such as higher-than-normal upper-mantle temperatures or thicker-than-normal crust, can be rejected on the basis of other geophysical information. Lithgow-Bertelloni and Silver have demonstrated that the cause may be in the lower mantle. From the most recent images of the Earth's interior produced by seismic tomography, they converted velocity anomalies into density anomalies and computed the mantle flow that would result. Low-density volumes generate upwelling flow, while regions of high density produce downwelling. These mantle convection currents tend to deform the shapes of overlying surfaces. Anomalously low seismic veloci-

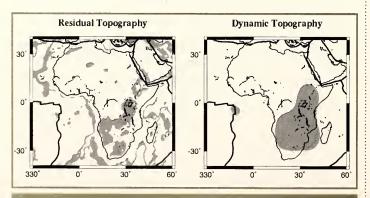


Fig. 5. Comparison of the topography of the African continent and the residual topography of the surrounding oceanic regions (left) with the dynamic topography predicted by the mantle flow calculation of Carolina Lithgow-Bertelloni (right). Regions with elevations above 500 m are shaded. High elevations of southern Africa are broadly consistent with the model.

ties (interpreted as regions of low density) extend beneath southern Africa through almost the entire vertical extent of the lower mantle. The upwelling currents predicted for such a region account well for the anomalous topography of the African continent (Fig. 5). This relationship provides a means by which the geological record of the uplift history of southern Africa may yield insight into the upwelling history of the lower mantle.

Current NSF Earth Sciences Research Fellow Andrew Freed has been working on the longstanding question of the forces driving the motions of the Earth's tectonic plates. Candidate forces can be divided between those that arise from density contrasts associated with the plates themselves, called self-driving forces, and those imparted by mantle convection currents not directly associated with the surface plates. Self-driving forces include the push of plates away from mid-ocean ridges contributed by the cooling and thickening of oceanic lithosphere and the pull of subducting slabs of cold and comparatively dense lithosphere at deep-sea trenches. Freed designed a numerical experiment to test whether self-driving forces are sufficient to explain the observed velocities and states of stress of the South American plate and the oceanic Nazca plate to its west. The experiment involved the construction of a mantle density structure from estimates of temperature and pressure, petrology, and experimental thermodynamic data, and a viscosity structure derived from temperature, pressure, laboratory deformation experiments, and observations of post-glacial rebound. He then developed a twodimensional dynamical model, incorporating these material properties, of a cross-section of the Earth's mantle beneath the Nazca and South American plates and spanning a region from the East Pacific Rise on the west to the Mid-Atlantic Ridge on the east. Freed found that he could predict the observed velocity and stress conditions with models that included only self-driving forces.

The behavior of Earth's geomagnetic field over the past several hundred years is relatively well known on the basis of measurements from satellites, observatories, and magnetic surveys such as those conducted by DTM earlier this century. To investigate the geomagnetic field over time scales of

thousands to millions of years, an important window on the dynamics of field generation in the Earth's fluid metallic core, one must turn to paleomagnetic records of field direction and intensity from lava flows or sediments. While the first-order characteristics of the field (its predominantly axial dipole structure, the existence of reversals) have been known for some time, the significance of shorter-wavelength, time-variable features has remained elusive. Such second-order features may relate to properties of the Earth's deep mantle, near the core-mantle boundary, which can influence motions in the outer core. Postdoctoral associate Catherine Johnson (now at the Incorporated Research Institutions for Seismology), along with Catherine Constable of the Scripps Institution of Oceanography, has utilized paleomagnetic data to document geomagnetic field behavior over the past 5 Myr. She has shown that the time-averaged structure of, and the temporal variations in, the global magnetic field are consistent with the influence of a heterogeneous lower mantle on core dynamics, but that improved paleomagnetic data sets are needed to test these ideas further. Her work has included the development of modeling techniques that assist in the selection of optimal new sampling locations to test for specific aspects of field behavior, on the basis of which she helped to establish a multi-institutional paleomagnetic sampling project that aims to improve substantially the distribution of paleomagnetic data from volcanic rocks younger than 5 Myr.

Postdoctoral associate Patrick McGovern has combined numerical models with observations to investigate the deformation of volcanoes, specifically how the mechanical properties of the crust and lithosphere beneath a volcano affect magma ascent paths and volcano growth. The latest data pertinent to the evolution of large volcanoes on the inner planets have come from precise altimetry now being carried out on Mars by the Mars Global Surveyor spacecraft. In contrast to expectations before this latest mission, most large volcanoes on Mars are not surrounded by topographic depressions—telltale signatures of flexure and subsidence of the underlying lithosphere in response to the load of the volcano—as are many oceanic volcanoes on Earth. McGovern deduced that any such depressions must be completely filled by vol-

canic material, either emplaced as flows (as with most large volcanoes on Venus) or as debris from failure of the flanks (as seen near some oceanic volcanoes on Earth). Circumferential faults around many large volcanoes on Mars had previously been attributed to stretching of the flexed martian lithosphere under the load of the central volcano. New altimetry data from the largest of those volcanoes, however, show that these faults lie well up the flanks of the volcanic edifice rather than in the surrounding lithosphere, as expected for a flexural origin. McGovern has shown that the position of these faults, and the stress field required for their formation, is best met if the volcano was subjected late in its history to uplift from below (e.g., by the intrusion of buoyant material, the development of a low-density mantle following melt extraction, or dynamic support from mantle convection).

Harry Oscar Wood Fellow Suzan van der Lee, now at the Federal Technical University in Zürich, Switzerland, spent much of her time at DTM investigating the structure of the Earth's mantle beneath the continents. For example, she utilized records of regional seismograms from broadband seismic experiments carried out by DTM and other groups to determine the three-dimensional structure of upper-mantle shear-wave velocity beneath central South America. Her analysis method, originated by Guust Nolet of Princeton University, yields particularly sharp images because wave shapes as well as arrival times are employed and both body waves and surface waves are included. Her latest



Harry Oscar Wood Fellow Suzan van der Lee in Zimbabwe, servicing the Mberengwa seismic station, part of the Southern Africa Seismic Experiment. This project involves more than 30 scientists from seven institutions in the U.S. and southern Africa.

model (Fig. 6), produced in collaboration with David James and Paul Silver, provides a detailed east-west profile of crust and mantle structure across the entire South American continent. Mantle structure is particularly variable, ranging from the very high seismic velocities of the ancient Brazilian craton in the east, to the moderately low velocities of the central basins, to the very low velocities in the west associated with the subduction of the Nazca plate and the ongoing mountain building of the Andes. The very low velocities beneath the crust of the Andes and above the subducting plate probably indicate that the mantle is partially molten in this region. Such melting is most likely attributable to volatiles, such as water, released from the oceanic crust of the subducting Nazca plate.

Postdoctoral associate Emilie Hooft makes use of seismic imaging to gain an understanding of magma transport from the mantle to the crust, specifically the process by which magma is focused from a broad source region (e.g., a zone of mantle upwelling beneath a mid-ocean ridge or a mantle plume) to the discrete volcanic systems observed at the surface. Having completed an analysis of seismic refraction data to image the magma focusing geometry at the centers of three segments of the Mid-Atlantic Ridge, she has recently turned her attention to the question of magma transport through the lower crust of Iceland, a ridge-centered hotspot with much higher rates of magmatism and much thicker crust than at a normal ridge. She is making use of earthquake records from a permanent network of seismic stations in southern Iceland, and in particular from the seismic coda, which is the part of the seismogram that follows recognizable arrivals. Energy propagation is complicated for this portion of the seismogram, but with modern seismic arrays and computer processing methods the underlying structure can be resolved and its relation to magma plumbing geometry unraveled.

Shear-wave splitting—an effect similar to the double refraction of light in crystals—is an important diagnostic for anisotropic regions of the Earth. Because the most common source of anisotropy in the upper mantle is the preferential alignment of olivine crystals by mantle flow processes, shear-

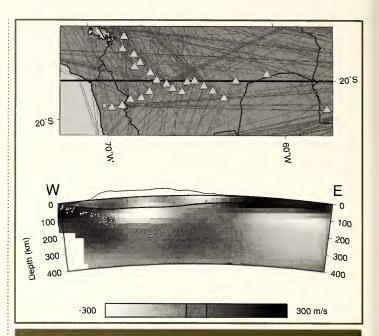


Fig. 6. (Bottom) Profile through Suzan van der Lee's shearwave velocity model for the central Andes region, where DTM carried out a portable broadband seismic experiment in 1996-1997. The topography along the profile (exaggerated by a factor of 10) and the inferred depth to the crust-mantle interface are also depicted. Earthquake hypocenters from the last 30 years are shown as dots. Gray tones in the cross section represent anomalies in shear wave velocity (in m/s) with respect to a reference model, which has a velocity of 4.5 km/s in the uppermost mantle. (Top) Map view of profile location, including earthquake epicenters (circles), stations (triangles), and wave paths used in the analysis.

wave splitting has been an important tool for mapping mantle convection patterns in subduction zones and other oceanic regions. The interpretation of the splitting observations has typically been based on simple one- or two-layer models of the anisotropic structure. Fellow Georg Rümpker, now at the GeoResearch Center in Potsdam, Germany, worked with Paul Silver last year on the effects of shear-wave propagation through more general models of anisotropic media. Using a variety of new techniques, he developed numerical codes to calculate synthetic waveforms, from which he computed shear-wave splitting parameters for comparison with observations. Rümpker demonstrated an important frequency-dependence of the splitting parameters, an effect that can provide information on the fine structure of the anisotropy but one that has usually been neglected in past interpretations. He showed further that depth-dependent anisotropy causes derived splitting parameters to vary with the polarization of the incident wavefront. By documenting these characteristics of more complex anisotropic structures, he

has laid the groundwork for testing three-dimensional models of mantle convection with shear-wave splitting observations.

Stephen Gao, a postdoctoral associate at DTM last year and now a visiting faculty member at Arizona State University, made use of records from DTM borehole strainmeters and other geodetic data to study the time-dependent slip of the San Andreas fault system in central California. While it has been known for some time that portions of the fault slip steadily and other sections remain locked for intervals of decades to centuries between major earthquakes, variations in slip at intermediate timescales remain little studied and poorly understood. Working with Alan Linde and Paul Silver, Gao documented a five-year interval during which the slip rate along the San Andreas fault first dropped below normal values for two years and then exceeded normal values for the three years that followed (Fig. 7). The cause of this deceleration and acceleration of fault slip is not known, but Gao and coworkers have speculated that an increase in annual rainfall at the start of the five-year interval may have initially loaded the surface, increasing normal stress across the fault, after which downward percolation may have increased pore pressure in the fault zone, lowering effective stress.

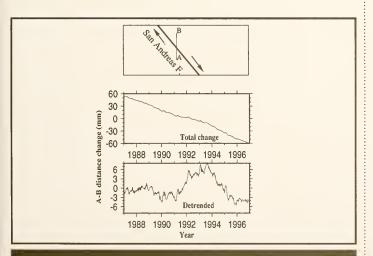


Fig. 7. Distance changes across the San Andreas fault near Parkfield, California, as measured by a two-color laser system, from the work of Stephen Gao. (Top) Sketch map of observation plan; baseline AB, approximately 10 km in length, straddles the fault zone. (Middle) Total changes in distance along line AB between 1987 and 1997. (Bottom) Residual distance changes over the same time interval, after removing the best-fitting long-term trend.

Wenjie Jiao, a joint postdoctoral associate of DTM and the Geophysical Laboratory, works with Paul Silver and Yingwei Fei on seismological and laboratory tests of proposed mechanisms for deep-focus earthquakes. Motivated by the rupture characteristics of the 1994 Bolivian deep earthquake, the largest deep event known, Silver had proposed that deep earthquakes occur on pre-existing planes of weakness created within the oceanic lithosphere at shallow depths. To test this hypothesis, Jiao compared the distribution of fault orientations of shallow and deep events for the Kurile subduction zone, where the geometry is particularly simple. On the basis of a statistical study of fault-plane solutions for 360 earthquakes in the Kurile subduction zone between 1970 and 1997, Jiao showed that the distribution of fault orientations for the deep events (after rotating by the dip angle of the subducted lithosphere) is indistinguishable from the distribution of orientations for the shallow events. Such an agreement would not be expected if the stress field in the subducted lithosphere, rather than preexisting zones of weakness, controlled fault orientations. While the mechanism of fault reactivation at great depth is not known, one possibility is that the dehydration at depth of hydrous phases concentrated within fault zones at shallow depth leads to some form of instability. It is this possibility that Jiao is now testing experimentally at the Geophysical Laboratory.

These brief summaries illustrate well the generalization that postdoctoral scientists play key roles in all areas of active research at DTM. That the postdoctoral component of the educational mission of the department, too, is achieving its aims can be at least partly demonstrated by the career paths these young scientists followed after leaving DTM. Of the 55 postdoctoral fellows and associates whose appointments ended between 1988 and 1998 and whose professional affiliation could be ascertained as of the fall of 1998, 90% are in academic or research positions at universities, observatories, or national laboratories. Merle Tuve's impassioned plea that the postdoctoral fellowship program should be the highest priority for institutional support remains as valid today as it was when penned sixty years ago.

PAGE 70

Department of Terrestrial Magnetism Personnel

July 1, 1997 - June 30, 1998

Research Staff Members

Conel M. O'D. Alexander L. Thomas Aldrich, Emeritus Alan P. Boss Louis Brown, Emeritus Richard W. Carlson John A. Graham Erik H. Hauri David E. James Alan T. Linde Vera C. Rubin I. Selwyn Sacks François Schweizer Steven B. Shirey Paul G. Silver Sean C. Solomon, Director Fouad Tera, Emeritus' George W. Wetherill

Senior Research Fellow

Frank D. Stacey, Merle A. Tuve Senior Fellow²

Postdoctoral Fellows and Associates

Richard D. Ash, Smithsonian-Camegie Fellow³ Harry J. Becker, NATO Postdoctoral Associate4 Kenneth M. Chick, Camegie Fellows Andrew M. Freed, NSF Earth Sciences Research Fellow⁶ Stephen Gao, NSF Associate Emilie E. E. Hooft, NASA Associate⁷ Wenjie Jiao, Camegie Fellow8,9 Catherine L. Johnson, NASA Associate¹⁰ Daniel D. Kelson, Barbara McClintock Fellow¹¹ Stephen J. Kortenkamp, NASA Associate John C. Lassiter, NSF Associate Jie Li, Grove Karl Gilbert Fellow^{8,12} Carolina Lithgow-Bertelloni, NSF Earth Sciences Research Fellow¹³ Hong Liu, NSF Postdoctoral Associate14 Stacy S. McGaugh, Carnegie Fellow¹⁵ Patrick J. McGovern, NASA Associate Bryan W. Miller, NASA Associate 16, 17 William G. Minarik, NSF Associate⁸ Larry R. Nittler, Camegie Fellow Michael W. Regan, Hubble Fellow¹⁸ Georg Rümpker, Camegie Fellow¹⁹ Paul B. Tomascak, Camegie Fellow Suzan van der Lee, Harry Oscar Wood Fellow^{8, 20} Harri A. T. Vanhala, NASA Associate

Predoctoral Fellows and Associates

Jaime Domínguez, Universidad Nacional Autónoma de México Kathryn Hoppe, Princeton University Hong Liu, University of California at Los Angeles Andrew H. Menzies, University of Cape Town

Jascha Polet, California Institute of Technology

Research Interns

Christopher J. Blay, University of Liverpool Caleb I. Fassett, Montgomery Blair High School, Maryland Sarah E. Faulkner, Brown University Caprice L. Gray, Massachusetts Institute of Matthew J. K. Runkle, Yale University Branson C. Stephens, Oklahoma Baptist University Andrew H. Waterman, Montgomery Blair High School, Maryland Karina Zavala, Northern Arizona University Sarah B. Zimmerman, St. Lawrence University

Michael J. Aciemo, Computer Systems Manager

Supporting Staff

John R. Almquist, Library Volunteer Maceo T. Bacote, Engineering Apprentices Georg Bartels, Instrument Maker Mary McDermott Coder, Senior Administrator H. Michael Day, Facilities Manager⁸ Roy R. Dingus, Building Engineer Janice Scheherazade Dunlap, Secretary to the Pablo D. Esparza, Maintenance Technician⁸ Rosa Maria Esparza, Clerk-Receptionist Shaun J. Hardy, Librarian® Mary Horan, Geochemistry Laboratory Manager Sandra A. Keiser, Scientific Computer Programmer William E. Key, Building Engineer8 Adriana Kuehnel, Library Volunteer Randy A. Kuehnel, Geophysical Technician P. Nelson McWhorter, Senior Instrument Maker Timothy D. Mock, Mass Spectrometry Laboratory Manager²¹ Ben K. Pandit, Electronics Engineer Lawrence B. Patrick, Maintenance Technician⁸ Daniela D. Power, Geophysical Research Assistant Pedro I. Roa, Maintenance Technician® Michael Seemann, Design Engineer-Mechanical, Shop Manager²⁰ Roy E. Scalco, Building Engineer⁸

Visiting Investigators

David Weinrib, Fiscal Assistant²²

Merri Wolf, Library Technical Assistant⁸

Terry L. Stahl, Fiscal Officer

Craig R. Bina, Northwestern University Ingi Th. Bjarnason, University of Iceland, Reykjavik Inés L. Cifuentes, Camegie Institution of Washington Timothy J. Clarke, New Mexico Institute of Mining and Technology Francis O. Dudás, Old Dominion University Jitendranath Goswami, Physical Research Laboratory, Ahmedabad, India Rosemary Hickey-Vargas, Florida International Tsuyoshi Ishikawa, Shizuoka University, Japan

Jianhua Wang, Ion Microprobe Research Specialist

Christopher R. Kincaid, University of Rhode Island Julie D. Morris, Washington University, St. Louis. Suzanne W. Nicholson, U.S. Geological Survey, Reston Jeffrey J. Park, Yale University

D. Graham Pearson, The University of Durham, Jeroen E. Ritsema, California Institute of Technology

Stuart A. Rojstaczer, Duke University Raymond M. Russo, Jr., Northwestern University Paul A. Rydelek, University of Memphis Martha K. Savage, Victoria University, New Zealand

Patrick O. Seitzer, University of Michigan Yang Shen, University of Rhode Island David W. Simpson, Incorporated Research Institutions for Seismology

J. Arthur Snoke, Virginia Polytechnic Institute and State University

Marian Tredoux, University of Cape Town Nathalie J. Valette-Silver, National Oceanographic and Atmospheric Administration John C. Van Decar, Nature Magazine, England

Elisabeth Widom, Miami University, Ohio

Joint appointment with the Smithsonian Institution and the

Geophysical Laboratory

To August 21, 1997

From September 1, 1997 From March 1, 1998

From November 1, 1997
Joint appointment with the Geophysical Laboratory

From July 15, 1997

¹⁰ To January 31, 1998

From December 22, 1997 From February 2, 1998

¹³ To July 7, 1997

⁴ From May 1, 1998

¹⁵ To September 30, 1997, and from May 1 to June 30, 1998

¹⁶ Joint appointment with the Space Telescope Science Institute ¹⁷ To September 30, 1997

20 To June 30, 1998

From January 5, 1998
Deceased September 14, 1998

From January 1, 1998

- Agustsson, K., A. T. Linde, R. Stefansson, and I. S. Sacks, Strain changes for the 1987 Vatnafjoll earthquake, south Iceland and possible magmatic triggering, J. Geophys. Res., in press.
- Alexander, C. M. O'D., and L. R. Nittler, The galactic chemical evolution of Si, Ti and O isotopes, Astrophys. J., in press.
- 5551 Alexander, C. M. O'D., S. S. Russell, J. W. Arden, R. D. Ash, M. M. Grady, and C. T. Pillinger, The origin of chondritic macromolecular organic matter: a carbon and nitrogen isotope study, Meteoritics Planet. Sci. 33, 603-622,
- 5557 Bank, C.-G., M. G. Bostock, R. M. Ellis, Z. Hajnal, and J. C. VanDecar, Lithospheric mantle structure beneath the Trans-Hudson Orogen and the origin of diamondiferous kimberlites, J. Geophys. Res. 103, 10103-10114, 1998. (No reprints available.)
- 5538 Barclay, A. H., D. R. Toomey, and S. C. Solomon, Seismic structure and crustal magmatism at the Mid-Atlantic Ridge, 35°N, J. Geophys. Res. 103, 17827-17844, 1998.
- 5520 Boss, A. P., Temperatures in protoplanetary disks, Annu. Rev. Earth Planet. Sci. 26, 53-80, 1998.
- 5526 Boss, A. P., Astrometric signatures of giant-planet formation, *Nature* 393, 141-143, 1998.
- 5534 Boss, A. P., The Jeans mass constraint and the fragmentation of molecular cloud cores, Astrophys. J. (Lett.) 501, L77-L81, 1998.
- 5546 Boss, A. P., Evolution of the solar nebula. IV. Giant gaseous protoplanet formation, Astrophys. J. 503, 923-937, 1998.
- 5548 Boss, A. P., Protostars and protoplanetary disks, Astrophys. Space Sci. 255, 15-23,
- 5550 Boss, A. P., The origin of protoplanetary disks, in *Origins: Proceedings of the International Conference*, C. E. Woodward, J. M. Shull, and H. A. Thronson, Jr., eds., pp. 314-326, Conference Series, Vol. 148, Astronomical Society of the Pacific, San Francisco, 1998.
- 5559 Boss, A. P., Looking for Earths: the Race to Find New Solar Systems, John Wiley & Sons, New York, 240 pp., 1998. (Available for purchase from the publisher and in bookstores.)
- 5560 Boss, A. P., Planet formation: twin planetary systems in embryo, *Nature 395*, 320-321, 1998.
- 5567 Boss, A. P., Binary star evolution: origin and formation, in Reports on Astronomy, Transactions of the International Astronomical Union, Vol. XXIIIA, I. Appenzeller, ed., pp. 385-387, Kluwer Academic Publishers, Dordrecht, 1997. (No reprints available.)
- Boss, A. P., Formation of extrasolar planets: core accretion or disk instability?, in Extrasolar Planets: Formation, Detection, and Modelling, R. Agostinho and F. Dos Santos, eds., Kluwer, Dordrecht, in press.

- Boss, A. P., Planets elsewhere: more surprises, Modem Astronomer, in press.
- Boss, A. P., C. A. Beichman, and H. A. Thronson, NASA and the search for extrasolar planets, in Extrasolar Planets: Formation, Detection, and Modelling, R. Agostinho and F. Dos Santos, eds., Kluwer, Dordrecht, in press.
- 5509 Boss, A. P., and P. N. Foster, Injection of short-lived isotopes into the presolar cloud, Astrophys. J. (Lett.) 494, L103-L106, 1998.
- 5547 Bresolin, F., R. C. Kennicutt, Jr., L. Ferrarese, B. K. Gibson, J. A. Graham, L. M. Macri, R. L. Phelps, D. M. Rawson, S. Sakai, N. A. Silbermann, P. B. Stetson, and A. M. Turner, et al., A Hubble Space Telescope study of extragalactic OB associations, Astron. J. 116, 119-130, 1998. (No reprints available.)
- 5517 Brown, L., "Sir Edward Victor Appleton," in Biographical Encyclopedia of Scientists, R. Olson, ed., pp. 41-43, Marshall Cavendish Corp., New York, 1998. (No reprints available.)
- 5518 Brown, L., "Walter Bothe," in Biographical Encyclopedia of Scientists, R. Olson, ed., pp. 192-195, Marshall Cavendish Corp., New York, 1998. (No reprints available.)
- 5519 Brown, L., "Richard Roberts," in Biographical Encyclopedia of Scientists, R. Olson, ed., pp. 1095-1097, Marshall Cavendish Corp., New York, 1998. (No reprints available.)
- 5561 Brown, L., "Daniel Bernoulli," in Biographical Encyclopedia of Mathematicians, D. R. Franceschetti, ed., pp. 45-47, Marshall Cavendish Corp., New York, 1998. (No reprints available.)
- 5562 Brown, L., "Oliver Heaviside," in Biographical Encyclopedia of Mathematicians, D. R. Franceschetti, ed., pp. 264-266, Marshall Cavendish Corp., New York, 1998. (No reprints available.)
- Brown, L., "Richard B. Roberts," in American National Biography, Oxford University Press, in press.
- 5568 Carlson, R. W., A conduit to the core, *Nature* 394, 11-12, 1998.
- Carlson, R. W., D. G. Pearson, F. R. Boyd, S. B. Shirey, G. Irvine, A. H. Menzies, and J. J. Gurney, Re-Os systematics of lithospheric peridotites: implications for lithosphere formation and preservation, in Proceedings of the 7th International Kimberlite Conference, in press.
- Chambers, J. E., and G. W. Wetherill, Making the terrestrial planets: N-body integrations of planetary embryos in three dimensions, Icarus, in press.
- de Blok, W. J. G., and S. S. McGaugh, Testing modified dynamics with low surface brightness galaxies—rotation curve fits, Astrophys. J., in press.
- 5578 Ferrarese, L., F. Bresolin, R. C. Kennicutt, Jr., A. Saha, P. B. Stetson, W. L. Freedman, J. R. Mould, B. F. Madore, S. Sakai, H. C. Ford, B. K. Gibson, J. A. Graham, M. Han, J. G. Hoessel, J. Huchra, S. M. Hughes, G. D. Illingworth, R.

- Phelps, C. F. Prosser, and N. A. Silbermann, The Hubble Space Telescope key project on the extragalactic distance scale. XII. The discovery of Cepheids and a new distance to NGC 2541, Astrophys. J. 507, 655-690, 1998. (No reprints available.)
- 5576 Frederiksen, A. W., M. G. Bostock, J. C. VanDecar, and J. F. Cassidy, Seismic structure of the upper mantle beneath the northern Canadian Cordillera from teleseismic traveltime inversion, Tectonophysics 294, 43-55, 1998. (No reprints availalble.)
- 5580 Gao, S., P. M. Davis, H. Liu, P. D. Slack, A. W. Rigor, Y. A. Zorin, V. V. Mordvinova, V. M. Kochevnikov, and N. A. Logatchev, SKS splitting beneath continental rift zones, J Geophys. Res. 102, 22781-22797, 1997. (No réprints available.)
- Gao, S., P. G. Silver, A. T. Linde, and I. S. Sacks, Annual modulation of triggered seismicity following the 1992 M_W=7.3 Landers earthquake, Nature, in press.
- 5501 Graham, J. A., 3 micron ice-band absorption in young stellar objects, Astrophys. J. 492, 213-218, 1998.
- 5536 Graham, J. A., Shocked gas and star formation in the Centaurus A radio galaxy, Astrophys. J. 502, 245-252, 1998.
- 5540 Graham, J. A., Star formation in the H I cloud associated with the NE radio lobe of NGC 5128 (Cen A), in The Second Stromlo Symposium: the Nature of Elliptical Galaxies, M. Árnaboldi, G. S. Da Costa, and P. Saha, eds., pp. 360-361, Conference Series, Vol. 116, Astronomical Society of the Pacific, San Francisco, 1997.
- 5499 Hauri, E. H., Melt migration and mantle chromatography, I: simplified theory and conditions for chemical and isotopic decoupling, Earth Planet. Sci. Lett. 153, 1-19, 1997.
- 5500 Hauri, E. H., and M. D. Kurz, Melt migration and mantle chromatography, 2: a timeseries Os isotope study of Mauna Loa volcano, Hawaii, *Earth Planet. Sci. Lett.* 153, 21-36, 1997.
- Hauri, E. H., D. G. Pearson, D. G. Bulanova, and H. J. Milledge, Microscale variations in C and N isotopes in mantle diaments revealed by SIMS, in Proceedings of the 7th International Kimberlite Conference, in press.
- 5514 Hill, R. J., L. Ferrarese, P. B. Stetson, A. Saha, W. L. Freedman, J. A. Graham, J. G. Hoessel, M. Han, J. Huchra, S. M. Hughes, G. D. Illingworth, D. Kelson, R. C. Kennicutt, Jr., F. Bresolin, R. Harding, A. Turner, B. F. Madore, S. Sakai, N. A. Silbermann, J. R. Mould, and R. Phelps, The extragalactic distance scale key project. V. Photometry of the brightest stars in M100 and the calibration of WFPC2, Astrophys. J. 496, 648-660, 1998. (No reprints available.)
- 5532 Huang, S., I. S. Sacks, and J. A. Snoke, Compressional deformation of island-arc lithosphere in northeast Japan resulting from long-term subduction-related tectonic forces: finite-element modeling, Tectonophysics 287, 43-58, 1998.

- 5535 Hughes, S. M. G., M. Han, J. Hoessel, W. L. Freedman, R. C. Kennicutt, Jr., J. R. Mould, A. Saha, P. B. Stetson, B. F. Madore, N. A. Silbermann, P. Harding, L. Ferrarese, H. Ford, B. K. Gibson, J. A. Graham, R. Hill, J. Huchra, G. D. Illingworth, R. Phelps, and S. Sakai, The *Hubble Space Telescope* extragalactic distance scale key project. X. The Cepheid distance to NGC 7331, Astrophys. J. 105, 32-53, 1998. (No reprints available.)
- 5570 Hutchison, R., C. M. O'D. Alexander, and J. C. Bridges, Elemental redistribution in Tieschitz and the origin of white matrix, *Meteoritics Planet. Sci.* 33, 1169-1179, 1998.
- 5498 Ishikawa, T., and F. Tera, Source, composition and distribution of the fluid in the Kurile mantle wedge: constraints from acrossarc variations of B/Nb and B isotopes, *Earth Planet. Sci. Lett.* 152, 123-138, 1997.
- _____ Ishikawa, T., and F. Tera, Two isotopically distinct fluid components involved in the Mariana arc: evidence from Nb/B and B-Sr-Nd-Pb isotope systematics, Geology, in press.
- _____ James, D. E., and I. S. Sacks, Cenozoic formation of the central Andes: a geophysical perspective, in *The Geology and Mineral Deposits of the Central Andes*, Special Publication No. 7, Society of Economic Geologists, Littleton, Colo., in press.
- 5505 Johnson, C. L., and C. G. Constable, The time-averaged geomagnetic field: global and regional biases for 0-5 Ma, *Geophys. J. Int.* 131, 643-666, 1997.
- 5511 Johnson, C. L., and C. G. Constable, Persistently anomalous Pacific geomagnetic fields, *Geophys. Res. Lett.* 25, 1011-1014, 1998.
- 5554 Johnson, C. L., J. R. Wijbrans, C. G. Constable, J. Gee, H. Staudigel, L. Tauxe, V.-H. Forjaz, and M. Salgueiro, ⁴⁰Ar/³⁹Ar ages and paleomagnetism of São Miguel lavas, Azores, *Earth Planet. Sci. Lett. 160*, 637-649, 1998.
- 5533 Kendall, J.-M., and P. G. Silver, Investigating causes of D" anisotropy, in *The Core-Mantle Boundary Region*, M. Gurnis et al., eds., pp. 97-118, Geodynamics Series, Vol. 28, American Geophysical Union, Washington, D.C., 1998.
- 5515 Kennicutt, R. C., Jr., P. B. Stetson, A. Saha, D. Kelson, D. M. Rawson, S. Sakai, B. F. Madore, J. R. Mould, W. L. Freedman, F. Bresolin, L. Ferrarese, H. Ford, B. K. Gibson, J. A. Graham, M. Han, P. Harding, J. G. Hoessel, J. P. Huchra, S. M. G. Hughes, G. D. Illingworth, L. M. Macri, R. L. Phelps, N. A. Silbermann, A. M. Turner, and P. R. Wood, The *Hubble Space Telescope* key project on the extragalactic distance scale. XIII. The metallicity dependence of the Cepheid distance scale, *Astrophys. J.* 498, 181-194, 1998. (No reprints available.)
- 5543 Koeberl, C., W. U. Reimold, and S. B. Shirey, The Aouelloul crater, Mauritania: on the problem of confirming the impact origin of a small crater, *Meteoritics Planet. Sci.* 33, 513-517, 1998.

- 5537 Kortenkamp, S. J., and S. F. Dermott, A 100,000-year periodicity in the accretion rate of interplanetary dust, *Science* 280, 874-876, 1998.
- 5571 Kortenkamp, S. J., and S. F. Dermott, Accretion of interplanetary dust particles by the Earth, *Icarus* 135, 469-495, 1998.
- ____ Lassiter, J. C., and E. H. Hauri, Osmium isotope variations in Hawaiian lavas: evidence for recycled oceanic lithosphere in the Hawaiian plume, *Earth Planet. Sci. Lett.*, in press.
- 5569 Linde, A. T., and I. S. Sacks, Triggering of volcanic eruptions, *Nature* 395, 888-890, 1998.
- 5504 Lithgow-Bertelloni, C., and M. A. Richards, The dynamics of Cenozoic and Mesozoic plate motions, *Rev. Geophys.* 36, 27-78, 1998. (No reprints available.)
- 5555 Lithgow-Bertelloni, C., and P. G. Silver, Dynamic topography, plate driving forces and the African superswell, *Nature* 395, 269-272, 1998.
- ____ Madore, B. F., W. L. Freedman, N. Silbermann, P. Harding, J. R. Mould, J. Huchra, J. A. Graham, L. Ferrarese, B. K. Gibson, M. Han, J. G. Hoessel, S. M. Hughes, G. D. Illingworth, R. Phelps, S. Sakai, and P. Stetson, The HST key project on the extragalactic distance scale. XV. Implications of a Cepheid distance to the Fornax cluster, *Astrophys. J.*, in press.
- 5553 Mandeville, C. W., A. Sasaki, G. Saito, K. Faure, R. King, and E. Hauri, Open-system degassing of sulfur from Krakatau 1883 magma, *Earth Planet. Sci. Lett. 160*, 709-722, 1998.
- 5565 McGaugh, S., and E. de Blok, The baryon fraction distribution and the Tully-Fisher relation, in *Galactic Halos: A UC Santa Cruz Workshop*, D. Zaritsky, ed., pp. 210-212, Conference Series, Vol. 136, Astronomical Society of the Pacific, San Francisco, 1998.
- 5527 McGaugh, S. S., and W. J. G. de Blok, Testing the dark matter hypothesis with low surface brightness galaxies and other evidence, *Astrophys. J.* 499, 41-65, 1998.
- 5528 McGaugh, S. S., and W. J. G. de Blok, Testing the hypothesis of modified dynamics with low surface brightness galaxies and other evidence, Astrophys. J. 499, 66-81, 1998.
- 5525 McGovern, P. J., and S. C. Solomon, Growth of large volcanoes on Venus: mechanical models and implications for structural evolution, *J. Geophys. Res.* 103, 11071-11101, 1998.
- 5522 MELT Seismic Team (D. W. Forsyth, D. S. Scheirer, S. C. Webb, L. M. Dorman, J. A. Orcutt, A. J. Harding, D. K. Blackman, J. Phipps Morgan, R. S. Detrick, Y. Shen, C. J. Wolfe, J. P. Canales, D. R. Toomey, A. F. Sheehan, S. C. Solomon, and W. S. D. Wilcock), Imaging the deep seismic structure beneath a mid-ocean ridge: the MELT experiment, *Science 280*, 1215-1218, 1998.

- Menzies, A. H., R. W. Carlson, S. B. Shirey, and J. J. Gumey, Re-Os systematics of Newlands peridotites: implications for diamond and lithosphere formation, in *Proceedings of the 7th International Kimberlite Conference*, in press.
- 5497 Miller, B. W., B. C. Whitmore, F. Schweizer, and S. M. Fall, The star cluster system of the merger remnant NGC 7252, Astron. J. 114, 2381-2401, 1997.
- Minarik, W. G., Complications for carbonate melt mobility due to the presence of an immiscible silicate melt, *J. Petrol.*, in press.
- Mukasa, S. B., A. H. Wilson, and R. W. Carlson, A multielement geochronology study of the Great Dyke, Zimbabwe: significance of the reset and robust ages, *Earth Planet. Sci. Lett.*, in press.
- 5508 Namiki, N., and S. C. Solomon, Volcanic degassing of argon and helium and the history of crustal production on Venus, *J. Geophys. Res. 103*, 3655-3677, 1998.
- 5574 Natta, A., and H. Butner, Resolving disks in YSOs, in *Infrared Space Interferometry:*Astrophysics & the Study of Earth-like Planets, C. Eiroa et al., eds., pp. 77-84, Kluwer Academic Publishers, Dordrecht, 1997. (No reprints available.)
- 5529 Nittler, L. R., C. M. O'D. Alexander, J. Wang, and X. Gao, Meteoritic oxide grain from supernova found, *Nature* 393, 222, 1998.
- 5513 Norabuena, E., L. Leffler-Griffin, A. Mao, T. Dixon, S. Stein, I. S. Sacks, L. Ocola, and M. Ellis, Space geodetic observations of Nazca-South America convergence along the central Andes, *Science* 279, 358-362, 1998.
- Pearson, D. G., and S. B. Shirey, Isotopic dating of diamonds, in *Application of Radiogenic Isotopes to Ore Deposit Research and Exploration*, Short Course Reviews in Economic Geology, Society of Economic Geologists, Littleton, Colo., in press.
- Pearson, D. G., S. B. Shirey, G. P. Bulanova, R. W. Carlson, and H. J. Milledge, Dating and paragenetic distinction of diamonds using the Re-Os isotope system: application to some Siberian diamonds, in *Proceedings of the 7th International Kimberlite Conference*, in press.
- Pearson, D. G., S. B. Shirey, G. P. Bulanova, R. W. Carlson, and H. J. Milledge, Single-crystal Re-Os isotope study of sulphide inclusions from a zoned Siberian diamond, *Geochim. Cosmochim. Acta*, in press.
- 5552 Pearson, D. G., S. B. Shirey, J. W. Harris, and R. W. Carlson, Sulphide inclusions in diamonds from the Koffiefontein kimberlite, S Africa: constraints on diamond ages and mantle Re-Os systematics, *Earth Planet. Sci. Lett.* 160, 311-326, 1998.
- 5542 Phelps, R. L., S. Sakai, W. L. Freedman, B. F. Madore, A. Saha, P. B. Stetson, R. C. Kennicutt, J. R. Mould, L. Ferrarese, H. C. Ford, B. K. Gibson, J. A. Graham, M. Han, J. G. Hoessel, J. P. Huchra, S. M. Hughes, G. D.

Illingworth, and N. A. Silbermann, The Hubble Space Telescope extragalactic distance scale key project. IX. The discovery of Cepheids in NGC 2090, Astrophys. J. 500, 763-788, 1998. (No reprints available.)

5510 Phillips, R. J., C. L. Johnson, S. J. Mackwell, P. Morgan, D. T. Sandwell, and M. T. Zuber, Lithospheric mechanics and dynamics of Venus, in Venus II, S. W. Bougher, D. M. Hunten, and R. J. Phillips, eds., pp. 1163-1204, University of Arizona Press, Tucson, 1997. (No reprints available.)

5539 Press, F., and R. Siever, *Understanding Earth*, 2nd ed., W. H. Freeman, New York, 682 pp., 1998. (Available for purchase from the publisher.)

5541 Rawson, D. M., L. M. Macri, J. R. Mould, J. P. Huchra, W. L. Freedman, R. C. Kennicutt, L. Ferrarese, H. C. Ford, J. A. Graham, P. Harding, M. Han, R. J. Hill, J. G. Hoessel, S. M. G. Hughes, G. D. Illingworth, B. F. Madore, R. L. Phelps, A. Saha, S. Šakai, N. A. Silbermann, and P. B. Stetson, The extragalactic distance scale key project. VIII. The discovery of Cepheids and a new distance to NGC 3621 using the Hubble Space Telescope, Astrophys. J. 490, 517-556, 1997. (No reprints available.)

5575 Righter, K., and E. H. Hauri, Compatibility of rhenium in garnet during mantle melting and magma genesis, Science 280, 1737-1741, 1998.

5558 Ritsema, J., A. A. Nyblade, T. J. Owens, C. A. Langston, and J. C. VanDecar, Upper mantle seismic velocity structure beneath Tanzania, east Africa: implications for the stability of cratonic lithosphere, J. Geophys. Res. 103, 21201-21213, 1998. (No reprints available.)

5506 Rubin, V., Dark matter in the universe, Scientific American Presents (special quarterly issue: Magnificent Cosmos) 9, no. 1, 106-110, 1998. (No reprints available.)

____ Rubin, V. C., Recollections after fifty years: Haverford AAS meeting, December 1950, in The American Astronomical Society's First Century, D. DeVorkin, ed., AIP Press, in press.

Rümpker, G., and P. G. Silver, Apparent shear-wave splitting parameters in the presence of vertically-varying anisotropy, Geophys. J. Int., in press.

5549 Russell, S. S., and A. P. Boss, Protostars and planets, Science 281, 932-933, 1998.

5563 Rydelek, P. A., and I. S. Sacks, Comment on "Crustal deformation measured in southem California," Eos, Trans. Am. Geophys. Union 79, 260, 1998.

____ Saal, A., S. R. Hart, N. Shimizu, E. H. Hauri, and G. D. Layne, Pb isotopic variability in melt inclusions from oceanic island basalts, Science, in press.

5530 Schweizer, F., Observational evidence for interactions and mergers, in Galaxies: Interactions and Induced Star Formation (Saas-Fee Advanced Course 26), D. Friedli, L. Martinet, and D. Pfenniger, eds., pp. 105-274, Springer, Berlin, 1998. (No reprints available.)

Schweizer, F., Overview: Low-z observations of interacting and merging galaxies, in Galaxy Interactions at Low and High Redshift, D. B. Sanders and J. E. Barnes, eds., IAU Symposium 186, Kluwer, Dordrecht, in press.

5572 Schweizer, F., and P. Seitzer, Ages and metallicities of young globular clusters in the merger remnant NGC 7252, *Astron. J.* 116, 2206-2219, 1998.

5556 Shen, Y., S. C. Solomon, I. Th. Bjarnason, and C. J. Wolfe, Seismic evidence for a lowermantle origin of the Iceland plume, Nature 395, 62-64, 1998.

5531 Shirey, S. B., and R. J. Walker, The Re-Os isotope system in cosmochemistry and high-temperature geochemistry, Annu. Rev. Earth Planet. Sci. 26, 423-500, 1998.

5507 Silver, P. G., Why is earthquake prediction so difficult?, Seismol. Res. Lett. 69, 111-113, 1998.

5502 Silver, P. G., R. M. Russo, and C. Lithgow-Bertelloni, Coupling of South American and African Plate motion and plate deformation, Science 279, 60-63, 1998.

5512 Smith, D. E., M. T. Zuber, H. V. Frey, J B. Garvin, J. W. Head, D. O. Muhleman, G. H. Pettengill, R. J. Phillips, S. C. Solomon, H. J. Zwally, W. B. Banerdt, and T. C. Duxbury, Topography of the northern hemisphere of Mars from the Mars Orbiter Laser Altimeter, Science 279, 1686-1692, 1998.

Stacey, F. D., Equations of state for close-packed materials at high pressures: geophysical evidence, J. Phys.: Condens. Matter, in

5544 Takanami, T., M. Kasahara, M. Takada, Y. Asai, I. S. Sacks, A. T. Linde, M. Aciemo, and B. Pandit, The new volume-strain observation system in Teshikaga, Hokkaido (in Japanese, with English abstract), Geophys. Bull. Hokkaido Univ. 61, 189-202, 1998.

5545 Takanami, T., T. Ogawa, I. S. Sacks, A. T. Linde, and I. Nakanishi, Long-period volumestrain seismogram of the 8 August 1993 Esashi-Oki earthquake, off southwest of Hokkaido, Japan and its source mechanism, J. Fac. Sci. Hokkaido Univ., ser. 7 (Geophys.) 11, 523-543, 1998.

Tomascak, P. B., F. Tera, R. L. Helz, and R. J. Walker, The absence of lithium isotope fractionation during basalt differentiation: new measurements by multi-collector sector ICP-MS, Geochim. Cosmochim. Acta, in press.

5523 Toomey, D. R., W. S. D. Wilcock, S. C. Solomon, W. C. Hammond, and J. A. Orcutt, Mantle seismic structure beneath the MELT region of the East Pacific Rise from P and S wave tomography, Science 280, 1224-1227,

5566 Turner, A., L. Ferrarese, A. Saha, F. Bresolin, R. C. Kennicutt, Jr., P. B. Stetson, J. R. Mould, W. L. Freedman, B. K. Gibson, J. A. Graham, H. Ford, M. Han, P. Harding, J. G. Hoessel, J. P. Huchra, S. M. G. Hughes, G. D.

Illingworth, D. D. Kelson, L. Macri, B. F. Madore, R. Phelps, D. Rawson, S. Sakai, and N. A. Silbermann, The Hubble Space Telescope key project on the extragalactic distance scale. XI. The Cepheids in NGC 4414, Astrophys. J. 505, 207-229, 1998. (No reprints available.)

5577 van der Lee, S., Observations and origin of Rayleigh-wave amplitude anomalies, Geophys. J. Int. 135, 691-699, 1998.

5579 van Dokkum, P. G., M. Franx, D. D. Kelson, and G. D. Illingworth, Luminosity evolution of early-type galaxies to z = 0.83: constraints on formation epoch and Ω , Astrophys. J. (Lett.) 504, L17-L21, 1998. (No reprints available.)

Vanhala, H. A. T., The triggered origin of the solar system, in *Proceedings of the* International Conference on "Isotopes in the Solar System," Indian Academy of Sciences, Bangalore, in press.

Vanhala, H. A. T., and A. G. W. Cameron, Numerical simulations of triggered star formation. I. Collapse of dense molecular cloud cores, Astrophys. J., in press.

5516 Wagner, T. P., D. A. Clague, E. H. Hauri, and T. L. Grove, Trace element abundances of high-MgO glasses from Kalauea, Mauna Loa and Haleakala volcanoes, Hawaii, Contrib. Mineral. Petrol. 131, 13-21, 1998.

5221 Wetherill, G. W., Contemplation of things past, Annu. Rev. Earth Planet. Sci. 26, 1-21, 1998.

Widom, E., K. Hoernle, S. B. Shirey, and H.-U. Schmincke, Os isotope systematics of the Canaries: implications for crustal and lithospheric mantle contamination, J. Petrol., in press.

5573 Williams, D. M., C. G. Mason, R. D. Gehrz, T. J. Jones, C. E. Woodward, D. E. Harker, M. S. Hanner, D. H. Wooden, F. C. Witteborn, and H. M. Butner, Measurement of submicron grains in the coma of comet Hale-Bopp C/1995 O1 during 1997 February 15-20 UT, Astrophys. J. (Lett.) 489, L91-L94, 1997. (No reprints available.)

5503 Wolfe, C. J., and P. G. Silver, Seismic anisotropy of oceanic upper mantle: shear wave splitting methodologies and observations, J. Geophys. Res. 103, 749-771, 1998.

5224 Wolfe, C. J., and S. C. Solomon, Shearwave splitting and implications for mantle flow beneath the MELT region of the East Pacific Rise, Science 280, 1230-1232, 1998.

5564 Wolfe, C. J., and F. L. Vernon III, Shearwave splitting at central Tien Shan: evidence for rapid variation of anisotropic patterns, Geophys. Res. Lett. 25, 1217-1220, 1998.

Zuber, M. T., D. E. Smith, R. J. Phillips, S. C. Solomon, W. B. Banerdt, G. A. Neumann, and O. Aharonson, Shape of the northern hemisphere of Mars from the Mars Orbiter Laser Altimeter (MOLA), Geophys. Res. Lett., in



THE DIRECTOR'S ESSAY:

The Geophysical Laboratory: Looking Back and Looking Forward

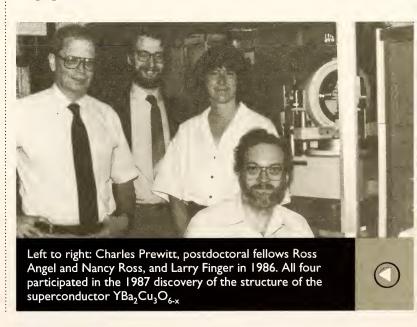
Because this is the last director's essay that I will write for the Carnegie Institution Year Book, I thought I would take the opportunity to reflect on the many things that have happened during my 12-year tenure. I feel privileged to have been director of the Geophysical Laboratory, and I am fortunate to continue to be associated with the Carnegie Institution. As the institution prepares for its first centennial celebration, I have no doubt that it will continue to be a leading scientific contributor for at least the next century.

Upton Street

When I arrived in Washington in the summer of 1986, the Lab was located in its original building on Upton Street in northwest Washington, D.C. The building, 80 years old at the time, was designed to be a research laboratory and was the locale for many important contributions to the geosciences. Although it had many limitations, the staff loved the place. Like the proverbial old shoe, it was somewhat worn down, but very comfortable.

One of the more interesting things that happened during my first few years at Upton Street was the discovery of high-temperature superconductors by Bednorz and Müller at the IBM Lab in Switzerland and the subsequent synthesis, by Paul Chu at the University of Houston, of another material, YBa₂Cu₃O_{6-x}, with an even higher transition temperature. Chu, a friend of Dave Mao, didn't have adequate laboratory apparatus to characterize this material, so he asked Dave for help. Thus began a very exciting series of events at the Lab. Several of us, including Dave, Rus Hemley, Bob

Hazen, Larry Finger, Chris Hadidiacos, myself, and postdocs Ross Angel and Nancy Ross, worked around the clock to perform x-ray diffraction and electron microprobe analyses on the sample. Despite having rather old equipment and being given misleading information about the sample, we were able to determine that Chu's sample actually was two different phases, only one of which was superconductive. As Bob Hazen wrote in his book about the adventure, The Breakthrough, we were the first to report a crystal structure for the material. Unfortunately, it wasn't quite right, and the fine details of structure and composition were eventually worked out by others at Bell Labs and elsewhere. Nevertheless, we learned a lot about the importance of having the talent, apparatus, and resources ready when an important challenge comes along. The fact that we were not very well prepared is one reason that I have made extensive efforts over the years to obtain adequate financial support for new equipment.



The year before I arrived at Carnegie, the president and trustees had begun to consider how to combine the Geophysical Laboratory and the Department of Terrestrial Magnetism in some way, perhaps moving everyone to another location. Invitations had been received from several leading universities to relocate on or near their campuses, and some of these options were very attractive. However, at the trustee's meeting in May 1986, the decision was made not to leave Washington, but to co-locate both departments on the grounds then occupied by DTM. A new research building would be built for both departments, and two existing structures—the main building and the cyclotron building—would be renovated. Planning for this co-location began immediately, and in May 1990, the Geophysical Laboratory personnel and much of their equipment, furniture, and "heirlooms" (many of which probably should have remained behind) were moved to the Broad Branch Road campus. We shared the new research building with DTM for almost a year while the main and cyclotron buildings were being renovated. Eventually, the administrative offices and library moved to the main building and the DTM geochemistry staff moved to the cyclotron building. Meanwhile, the old Geophysical Laboratory building on Upton Street was sold and is now a school of music.

In looking back, it is difficult to understand why life in the old Lab was so attractive. Much of the scientific equipment was very outdated. The electrical and water distribution systems were limited. (I remember spending most of one Christmas day with several others mopping up water after a pipe burst in the attic, probably because instruments were shut down and the water pressure was unusually high.) We had only four telephone lines to the outside world. (An old-fashioned chime system



notified people of incoming calls.) As well, there was very little air circulation; cooling in the hot Washington summers relied on strategically located window air conditioners. For computing, we relied on a Digital Equipment Corp. VAX 11-780 that we shared with DTM. We entered the current computer age only reluctantly with the purchase of a few microcomputers. Nevertheless, I think people were happy then, and now that we have moved and corrected many of the "teething" problems with the new facility, are happy that the move took place.

Changes

In the years since moving to the Broad Branch Road campus, many things have changed. Owing to a concerted effort by the staff and with financial support from president Singer, the trustees, and various federal and private funding agencies, we now have excellent and competitive scientific equipment and the means to keep it operating in good condition. We are connected to the world via the internet and, after some missteps, are developing extensive computer capabilities. These range from accommodation of complex theoretical codes on a Cray mini-supercomputer to microcomputer access for everyone in the department. One indicator of change is that computers now provide the graphics support that previously required two darkrooms. These rooms—considered essential when the new building was designed—have since been converted to spectroscopy laboratories. Another indicator of change, a more personal one, is that we are now receiving many of our best postdoctoral applications from other countries. We have postdocs and predocs from China, Japan, Russia, Germany, France, Switzerland, Turkey, and Poland, in addition to those from the United States.

Earth science itself is changing. Mining and petroleum extraction used to be major objectives of the earth science community in the United States. Now, mining has largely moved overseas, as have the major initiatives in petroleum exploration and production, some located in regions near or in the former Soviet Union. At the same time, various factors, including the end of the Cold War, have greatly reduced the urgency associated with assuring an adequate supply of mineral resources. Oil is abundant and prices are at a relative long-term



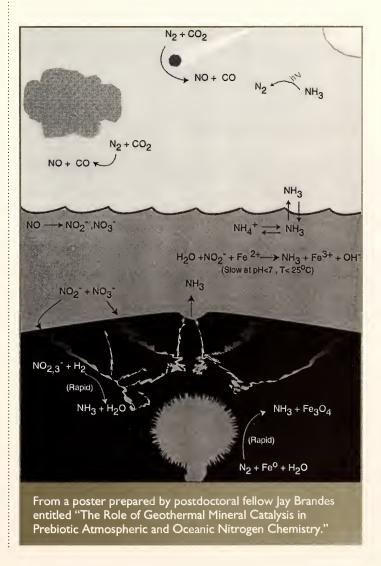


Members of the Geophysical Laboratory, First row, from left: G. Cody, D. Mao, R. Hazen, Y. Fei, P.E. Hare, C. Prewitt, H. Yoder, M. Fogel, D. Virgo, B. Mysen, R. Hemley, and J. Boyd. Second row: G. Zou, J. Shu, W. Xiao, V. Joe, S. Faulkner, A. Jayaraman, Y. Ma, P. Conrad, J. Brandes, D. George, S. Schmidt, M. Bacote, A. Antoszyk, M. Fantle, U. Wiechert, Y. lizuka, P. Meeder, T. Filley, S. DeSantis, R. Filley, P. Esparza, and N. Boctor. Third row: W. Pike, R. Praseuth, B. Scott, E. Bloomfield, H. Hibbert, A. Berengaut, X. Noblin, M. Somayazulu, A. Goncharov, H. Yang, V. Struzhkin, and Y. Frieman. Fourth row: C. Bertka, D. Von Endt, M. Imlay, S. Gramsch, S. Coley, W. Jiao, S. Merkel, G. Sághi-Szabó, L. Patrick, R. Dingus, B. Collins, J. Straub, R. Scalco, C. Hadidiacos, H. Fricke, K. Wheeler, and J. Badro

low. Because of these trends and related perceived shifts in attitude of politicians and opinion setters, American university geoscience departments are emphasizing more societal-based programs, such as environmental science, hydrology, and hazard reduction. However, I believe there is still a need for research at the fundamental level that has always characterized the objectives of the Geophysical Laboratory. We are holding to that tradition, as we continue to pursue fundamental research in petrology, geochemistry, biogeochemistry, mineral physics, and, increasingly, materials science, physics, and chemistry.

At the same time, we are constantly on the lookout for new challenges. With DTM, for example, we recently became a part of the NASA-sponsored Astrobiology Institute, initiated at least partly because of excitement generated by suspected signs of former life in a Martian meteorite. Whether or not these meteorites do contain such evidence, the search for clues about the origin of life is a very exciting and important research direction. Even if we never really do learn how life began, there are already developments here and elsewhere that would not have taken place without the funding and encouragement of the Astrobiology Institute and other related initiatives. Bob Hazen, George Cody, Hatten Yoder, and Marilyn Fogel have demonstrated how fundamental geoscience backgrounds can be of considerable use in tackling problems that require a wide range of knowledge

and techniques. One example of their work is the application of traditional inorganic hydrothermal synthesis techniques to the synthesis of organic compounds at moderate pressures and temperatures. As new and redirected resources become

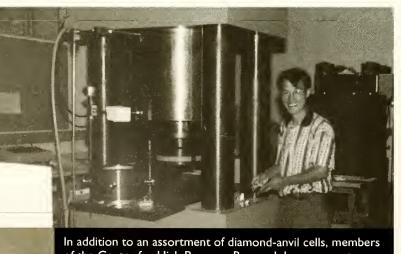


available, they will undoubtedly result in many other new discoveries.

Mineral Physics

Before joining the Lab, I was a member of a National Research Council committee convened to review and eventually produce a report on the current state of research in mineral physics. The committee met several times, conducted a workshop for about 60 people at Airlie House in Virginia, and produced a report, "Physics and Chemistry of Earth Materials," widely known as the "PACEM" Report. The report recommended special attention and increased funding for several different areas in mineral physics, including synchrotron radiation for experiments, high-pressure science and technology, accelerator mass spectroscopy, and apparatus for rock deformation experiments. All of these eventually received substantial funding increases and are today significant components of geological research.

But just what is mineral physics? Mineral physics is a growing and important discipline in the earth sciences that concentrates on the physical and chemical properties of minerals. Its practitioners—a broad range of scientists—study how knowledge of these properties can contribute to the understanding of major geological phenomena. One of



of the Center for High Pressure Research have access to such instruments as this multi-anvil press, shown here with Yingwei Fei. The first such multi-anvil press in the USA (purchased from the Sumitomo Company of Japan) was installed at SUNY Stony Brook in the mid-1980s. Since then, several dozen presses of varying design have been built in the USA and abroad, and are in use in laboratories around the world. The press in this photo was made in Baltimore.

their major goals is to explore the crystal chemical constraints imposed by the high temperatures and high pressures within the Earth and to provide an overview of the dominant phases resulting from mixtures of the major elements (O, Si, Fe, and Mg) under these conditions. The pioneers, including Bernal, Goldschmidt, Bridgman, Birch, and Ringwood, made essential contributions to understanding how earth materials combine, dissociate, and transform as environmental conditions change. However, it has only been in the last 10 to 20 years, with the development of new instrumentation for x-ray diffraction and spectroscopy, particularly synchrotron sources, that we have had access to the experimental and theoretical tools that allow us to confirm or dispute the ideas of the pioneers and to make a priori predictions of what will happen when a particular mineral composition is subjected to specific conditions of temperature, pressure, or stress.

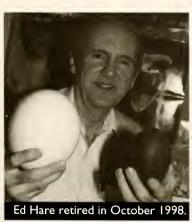
Much current research at high pressure involves learning how the major elements form phases and how transitions take place in them as we simulate Earth's interior in laboratory apparatus or on computers. The phases of magnesium-iron silicates serve as model systems for studies of high-pressure structures, phase transitions, vibrational dynamics, and chemical bonding. In view of the wide-ranging importance of the high-pressure behavior of oxides, silicates, and sulfides, the literature on this subject is extensive and growing, but far from complete. Recent discoveries include new phases, electronic and magnetic transitions, contrasting results from hydrostatic or differential stress, insight into the role of hydrogen, and information about how specific phases respond to changing conditions. These studies have important implications for geology, planetary science, materials science, and fundamental physics.

Most of our mineral physicists are associated with the Center for High Pressure Research, a consortium funded by the National Science Foundation's Science and Technology Center Program and including the Geophysical Laboratory, State University of New York at Stony Brook, University of California at Davis, and University of California at San Diego. The center conducts research in both

high-pressure science and technology and in using synchrotron-generated x-ray and infrared beams for a variety of experiments in diffraction and spectroscopy. We are now in our eighth year of operation, and we are scheduled to run for an additional three years, when the current grant will end. NSF policy states that, after 11 years, existing S&T Centers cannot continue to be funded to do the same kind of research they do at present. It is not clear, however, if this means that they will be terminated at the end of 11 years, or if other kinds of funding will be available. Whatever the outcome, the center has had an enormous influence on high-pressure science and technology all over the world. Our former postdocs occupy important positions in other research institutions and facilities, and produce excellent science in their own right.

Biogeochemistry

Biogeochemistry has been an important part of Geophysical Laboratory research for many years, and I believe it should be continued and even expanded in the future. It ties in well with NASA's new astrobiology program, to which GL/DTM personnel are major contributors, and it overlaps our program in geochemistry. The biogeochemistry effort was begun some 50 years ago when former GL director Phil Abelson crushed a handful of 25-million-year-old clam shells and proceeded to extract amino acids. Eventually, Abelson hired Tom Hoering and Ed Hare, who were later joined by Marilyn Fogel during Hatten Yoder's term as director. This trio, their postdocs and predocs, and collaborators from other institutions made major contributions to biogeochemistry over the years and laid a solid



foundation for future research at the Geophysical Laboratory. When Tom Hoering retired, I hired George Cody, who is adding new dimensions to the research efforts, particularly in organic geochem-

istry and the macromolecular structure of bio- and geo-polymeric organics.

Of the original biogeochemistry trio, only one— Marilyn Fogel—remains. Ed Hare retired in October 1998. Last April, we held a conference, "Perspectives in Amino Acid and Protein Geochemistry," in honor of his retirement. Organized by Glenn Goodfriend, John Wehmiller, and Steve Macko, the conference was held at the American Geophysical Union building in downtown Washington. It was a great success and a fitting tribute to Ed's very significant scientific contributions. Ed worked on amino acid geochemistry through much of his career and influenced a large number of scientists in a variety of related disciplines. At the conference, he received an impressive "family tree" showing the connections between him, his immediate co-workers, and their postdoc and predoc "descendants." His friends also gave Ed and his wife, Patti, a gift of a raft trip down the Colorado River.

Petrology and Geochemistry

Petrology, or the study of rocks, is perhaps the most established part of research at the Geophysical Laboratory. While the techniques of petrology have evolved through the years, the goal remains the same—to understand how rocks on the Earth were formed and how they evolved with time. Geochemistry as a discipline is much broader than petrology in the sense that it involves the chemistry of virtually everything that exists on Earth, particularly if biogeochemistry is included.

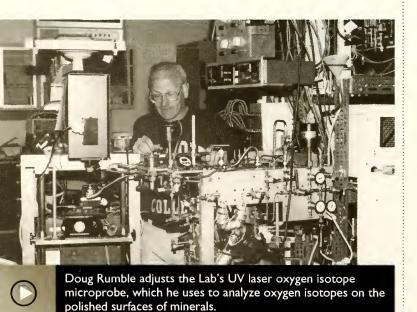
Our petrologists and geochemists pursue a broad range of topics, and often collaborate with scientists of other disciplines. There are such geographically-diverse, field-related projects as Neil Irvine's long-term study of the Skaergaard igneous complex in Greenland, Joe Boyd's work on the Kaapvaal craton in South Africa, and Doug Rumble's stable isotope analyses of high-pressure metamorphic rocks from China. Also included are application of contemporary analytical approaches, such as Bjørn Mysen's and John Frantz's high-temperature, high-pressure Raman spectroscopy of silicate melts and fluids, and Dave Virgo's analytical work on the hydrogen content of amphiboles.

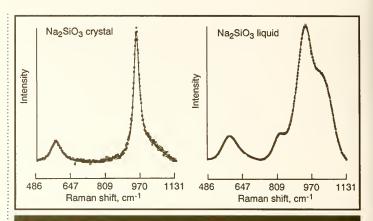
Hatten Yoder, whose distinguished record in experimental petrology is recognized around the world, has become an essential contributor to the astrobiology effort through his experiments synthesizing organic compounds under hydrothermal conditions.

There exists such a continuum of interests among the fields described here, in fact, that categorizing people as belonging to a specific discipline, while convenient administratively, is misleading and obscures the connections that exist between people and their research. For example, a petrologist using Raman spectroscopy to investigate silicate melts and a geochemist using NMR spectroscopy for studies of coal can both be called mineral physicists. The important thing is that we do collaborate and make the best of all available talents and resources.

Other Institutions

One of the wonderful things about science is its international network, enabling scientists to maintain professional interactions with people all over the world. We communicate because of common interests. This is true for institutions as well as for individuals. I know, for example, of two other laboratories that share the interests and research objectives of the Geophysical Laboratory, and we maintain close ties with both. One is the Bayerisches Geoinstitut in Bayreuth, Germany. This institute was organized in 1986 with funding primarily from the Bayarian government. Its first director was





Raman spectra show the transformation from a crystal (left) to a liquid (right) of Na_2SiO_3 at the melting point of $1201^{\circ}C$. The spectra indicate that a change in molecular shape has occurred, from long SiO_4 chains to isolated SiO_4 tetrahedra that coexist with chains and sheets. It also demonstrates the close relationship between current investigations involving information from both petrology and mineral physics.

Friedrich Seifert, a GL staff member in the 1970s. The other institution with similarities to our own is the Institute for Study of Earth's Interior (ISEI) in Misasa, Japan. Its most recent director is Ikuo Kushiro, also a former GL staff member. Kushiro left Washington to become a professor and eventually a vice-president at the University of Tokyo before joining the ISEI. Although most of ISEI's support comes from the Japanese Ministry of Education, Monbusho, its research program is in many ways similar to that of a combined GL and DTM. Examples of collaboration include a joint ISEI/GL seminar ("Evolutionary Processes of Earth and Planetary Materials") during June 1996, coupled with tours of the Misasa facilities and a field trip to Hokkaido to visit recently active volcanoes and to view rocks derived from the upper mantle. In October 1997, scientists from ISEI, the Bayerisches Geoinstitut, and the Geophysical Laboratory, along with members of the Philippine Volcano Institute and a number of guests from several different countries, held a conference, "Materials Recycling Near Convergent Plate Boundaries," in the Philippines that also included field trips, this time to the Taal and Pinatubo volcanoes. The idea was to discuss common research interests and to exchange ideas about the future. These conferences were so successful that we've scheduled another for September 1999 in northern Italy. In addition to these periodic assemblies, there is constant interchange of personnel and research topics among the laboratories and frequent encounters at international meetings.



In a "clean lab" at the Institute for Study of the Earth's Interior, Misasa, Japan, (left to right) Victor Kress, Bjørn Mysen, Dave Virgo, and Joe Boyd (far right) listen as ISEI's Eizo Nakamura (second from right) describes his research.

Finances

Financial support for staff, postdoctoral, and predoctoral salaries, research expenses, equipment, and general operating expenses are always a concern of the director and the Carnegie administration. Before the 1970s, the Lab was largely run by income from the Carnegie endowment. During the 1970s, primarily because of the NASA Lunar Sample Program, a few federal research grants were obtained to cover personnel, equipment, and other research expenses. The fraction of expenses covered by grants began to grow substantially after I became director, especially after we were awarded the NSF Science and Technology Center grant for the Center for High Pressure Research. If equipment funds are included, about 50% of our total income today comes from sources external to the Carnegie Institution. This is not a comforting trend. It is important for the institution to address future funding requirements and resources and be ready to react positively if a crisis occurs.

The Future

What about the future? Where are we going from here? In recent years, a major departure from the traditional geoscience program at the Lab has been the increasing involvement of our personnel in areas more akin to materials science and physics than earth science. This is possible because of GL's substantial commitment to the frontiers of high-pressure research, and the growing interest in high-pressure phenomena among the materials

science and physics communities. The Geophysical Laboratory is in a position to be a major player in this field, which is relatively small compared to many other parts of materials science and physics. With colleagues from Lawrence Livermore Laboratory and the University of Nevada at Las Vegas, David Mao and Russell Hemley are leading an effort to fund, design, build, and operate equipment devoted to highpressure experiments at the Advanced Light Source (APS) synchrotron facility at Argonne National Laboratory. The equipment, called a "sector," consists of two x-ray beam ports and associated real estate. Although just in the preliminary planning stage, this initiative has a good chance of success and represents a substantial commitment of the institution, not only for material support but to a very specific direction for future research. The initial investment for construction is about \$10 million, and will require additional, ongoing support for operation, maintenance, and new developments. This represents an exciting new departure for the Lab, but it also means that a significant fraction of our research will be taking place at a remote location, perhaps not much different from operating a telescope in a location removed from an astronomy department.

Research in other directions is very much open and will depend largely on decisions the new director makes in replacing retiring staff, on the continued search for financial support, and on the national and international trends that affect the scientific community. Clearly, there is great international interest in the inorganic/organic interface in geochemistry, and universities are seeking bright young graduates with related training. Petrologists are extending their reach from the Earth to solving problems in planetary science. We are learning more every day about how the solar system formed and it is likely that other similar systems will be identified and investigated in coming years. The fundamental research discussed above will always be applicable to new and exciting scientific challenges, and I believe the Geophysical Laboratory will continue to be one of the leading scientific establishments in the years to come.

Research Staff Members

Francis R. Boyd, Jr., Petrologist Emeritus George D. Cody Ronald E. Cohen Yingwei Fei Larry W. Finger Marilyn L. Fogel John D. Frantz P. Edgar Hare Robert M. Hazen Russell J. Hemley T. Neil Irvine Ho-kwang Mao Bjørn O. Mysen Charles T. Prewitt, Director Douglas Rumble III David Virgo Hatten S. Yoder, Jr., *Director Emeritus*

Senior Fellows and Associates

Peter M. Bell, Adjunct Senior Research Scientist

Constance Bertka, Senior Research Associate, National Aeronautics and Space Administration (NASA) and Center for High Pressure Research (CHiPR)2 Paula Davidson, Department of Energy (DOE) Associate³ Alexandre Goncharov, Senior Research Associate (CHiPR) Glenn A. Goodfriend, Senior Postdoctoral Associate, National Science Foundation (NSF)3 Kei Hirose, Tokyo Institute of Technology Fellow Jingzhu Hu, Research Technician (NSF) Jürgen Konzett, Swiss National Science Foundation Fellow⁵ Gotthard Sághi-Szabó, Senior Research Scientist⁶ Jinfu Shu, Research Technician (CHiPR) Viktor Struzhkin, Senior Research Associate (CHIPR) Uwe Wiechert, Deutsche Forschungsgemeinschaft (DFG) Fellow Chang-Sheng Zha, Research Technician (CHiPR)7

Postdoctoral Fellows and Postdoctoral Research Associates

Richard D. Ash, Smithsonian Institution and Carnegie Fellow⁸ James Badro, CHiPR Associate⁹ David R. Bell, NSF Associate¹⁰ Jay A. Brandes, Camegie Fellow James Farquhar, Camegie Fellow¹¹ Timothy R. Filley, Camegie Fellow¹² Henry C. Fricke, NSF Associate¹³ Daniel J. Frost, CHiPR Associate14 Stephen A. Gramsch, CHIPR Associate15 Oguz Gülseren, NSF Associate16 Yoshiyuki lizuka, CHIPR Associate Joel J. Ita, NSF Associate7 Wenjie Jiao, NSF Associate and Carnegie Fellow¹⁷ Jürgen Konzett, CHiPR Associate¹⁸ Jie Li, Gilbert Fellowⁱ⁹ Wei Li, CHiPR Associate²⁰ Ren Lu, NSF Associate²¹ William Minarik, NSF Associate and Carnegie Fellow³³ Yanzhang Ma, CHIPR Associate Gotthard Sághi-Szabó, Office of Naval Research (ONR) Associate²² Thomas A. Schindelbeck, Deutsche

Forschungsgemeinschaft Fellow²³ Madduri S. Somayazulu, Carnegie and Arizona State

Mark A. Teece, Camegie & Smithsonian Institution Research Associate²⁵

Suzan van der Lee, Hany Oscar Wood Fellow²⁶ Hexiong Yang, Hazen Gift

Predoctoral Fellows and Predoctoral Research Associates

Pamela G. Conrad, CHiPR Associate Subarnarekha De, Carnegie Fellow²⁷ Sébastien Merkel, NSF and CHIPR Associate²⁸ Sean Shieh, Carnegie Fellow

Summer Interns, Geoscience Program (NSF)

AnnMarie Accardi, Rensselaer Polytechnic Institute29 Mark Acton, Williams College25 Alexander Berengaut, Montgomery Blair High School¹⁸ Emily Bloomfield, Case Western Reserve University's Stacia DeSantis, Dartmouth College 18 Sarah Faulkner, Brown University Stephen Hadley, Union College 18 Heather Hibbert, Princeton University¹⁸
Valerie Joe, State University of New York at Stony Brook¹⁸
Stephanie Kitchel, State University of New York at Stony Brook²⁹ Nora Klein, Brown University29 David Lawler, Haverford College²⁹ Vincent Lim, University of Virginia²⁹ Xavier Noblin, École Normale Supérieure de Lyon, France¹⁸ William Pike, Carleton College¹⁸ Richard Praseuth, Mt. San Antonio College¹⁸ Bryan Wade Scott, Howard University¹⁸ Audrey Slesinger, Tufts University29 Michelle Weinberger, University of Pennsylvania²⁹ Kevin Wheeler, Brown University¹⁸

Research Interns

Rehan Ali, Broad Run High School, Ashbum, VA³⁸ Mark Acton, Montgomery Blair High School⁵⁹ Benjamin Cooper, Georgetown Day High School™ Virginie Pinel, École Normale Supérieure de Lyon, France³⁹ Jacob Waldbauer, Georgetown Day School*

Supporting Staff

John R. Almquist, Library Volunteer Andrew J. Antoszyk, Shop Foreman Maceo T. Bacote, Engineering Apprentice³³ Bobbie L. Brown, Instrument Maker Stephen D. Coley, Sr., Instrument Maker H. Michael Day, Facilities Manager³³ Roy R. Dingus, Building Engineer Pablo D. Esparza, Maintenance Technician33 Rose Filley, Research Technician³ David J. George, Electronics Technician Christos G. Hadidiacos, Electronics Engineer Shaun J. Hardy, Librarian 33 Marjorie E. Imlay, Assistant to the Director William E. Key, Building Engineer³³ Adriana Kuehnel, Library Volunteer35 Paul Meeder, Administrative Assistant Lawrence B. Patrick, Maintenance Technician³³ Pedro J. Roa, Maintenance Technician³ Roy E. Scalco, Engineering Apprentice³³ Susan A. Schmidt, Coordinating Secretary John M. Straub, Business Manager Mark Wah, Instrument Maker Merri Wolf, Library Technical Assistant³³

Visiting Investigators

Brigitte Behrends, Deutsche Akademische

Austauschdienst, Bonn Ben Burton, National Institute of Standards and Technology Nabil Z. Boctor, Washington, D. C. Alison Brooks, George Washington University John V. Badding, Pennsylvania State University David R. Bell, Cape Town, South Africa C. Page Chamberlain, Dept. Earth Sciences, Dartmouth College I. Ming Chou, U. S. Geological Survey Jean Dubessy, Centre de Recherches sur La Géologie des Matières Premières Minérales et Énergetiques, Vandoeuvre-Les-Nancy, France
Thomas S. Duffy, University of Chicago
Joseph Feldman, Naval Research Laboratory

Yuri Frieman, Verkin Institute of Low-Temperature Physics and Engineering, Ukrainian Academy of Sciences, Kharkov, Ukraine Reto Gieré, University of Basel, Switzerland Hans G. Huckenholz, Mineralogisch-Petrographisches Inst

der Ludwig-Maximilians-Univ. München

Donald G. Isaak, University of California, Los Angeles Boris Kiefer, University of Michigan Deborah Kelley, University of Washington

Amy Y. Liu, Dept. of Physics, Georgetown University³⁷
Allison M. Macfarlane, George Mason University
Ryan P. McCormack, National Institute of Standards

and Technology Charles Meade, National Research Council,

Washington, D.C. Harold Morowitz, George Mason University Nicolai P. Pokhilenko, Institute of Mineralogy and

Petrology, Novosibirsk, Russia
Robert K. Popp, Texas A&M University
Anil K. Singh, National Aerospace Laboratories,

Anii K. Singir, National Petrology,
Bangalore, India
Nicolai V. Sobolev, Institute of Mineralogy and Petrology,
Academy of Sciences, Novosibirsk, Russia
Gerd Steinle-Neumann, University of Michigan Lars Stixrude, University of Michigan Mikhail Strzhemechny, Verkin Institute of Low-

Temperature Physics and Engineering, Ukrainian

Academy of Sciences, Kharkov, Ukraine
Academy of Sciences, Kharkov, Ukraine
Noreen C. Tuross, Smithsonian Institution
David von Endt, Smithsonian Institution
Qingchen Wang, Chinese Academy of Sciences
Wansheng Xiao, Institute of Geochemistry, Chinese

Academy of Sciences, Guangzhou, China Hak Nan Yung, Chinese Academy of Sciences, Guangzhou

Ru-Yuan Zhang, Stanford University Yi-Gang Zhang, Academia Sinica, China Guangtian Zou, Director of Center for Superhard Materials, Jilin University, Changchun, China

To June 30, 1998 as Director, Research Staff, from July 1, 1998.

*From February 1998; Center for High Pressure Research

*To February 28, 1998.

*To March 27, 1998.

To May 31, 1998

From July 18, 1997

⁷To January 31, 1998 loint appointment with the Smithsonian Institution and DTM

From December 12, 1997

**To July 1, 1997

"To August 31, 1997
"From October 1, 1997
"From September 8, 1997
"To October 1, 1997

From September 1, 1997 From March 2, 1998

V From July 14, 1997 to Dec. 31, 1997; Joint appointment with DTM from Jan. 1, 1998

*From June 1, 1998

From February 1, 1998; joint appointment with DTM To January 18, 1998

²⁴ To January 2, 1998. ²² To July 17, 1997. ²³ To July 1, 1997.

²⁴To April 15, 1998 ²⁵From September 2, 1997 ²⁴To June 30, 1998; joint appointment with DTM

²⁷ From February 9, 1998

28 From October 10, 1997

³⁹ From June 11, 1997 ³⁰ From June 16, 1997

³ From June 23, 1997 ³ From May 5, 1997

³³ Joint appointment with DTM ³⁴ From September 22, 1997

35 From August 28, 1996; joint appointment with DTM

*To January 6, 1998 *To To August 1, 1996 *To August 1, 1997 *To September 1, 1997

To August 12, 1997

"To September 9, 1997

Geophysical Laboratory Bibliography

- Aguilar, C., M. L. Fogel, and H. W. Paerl, Dynamics of atmospheric inorganic utilization in the coastal waters of North Carolina, Mar. Ecol. Prog. Ser.,
- 2682 Bertka, C. M., and Y. Fei, Density profile of an SNC model Martian interior and the moment-of-inertia factor of Mars, Earth Planet. Sci. Lett. 157, 79-88,
- 2714 Bertka, C. M., and Y. Fei, Implications of Mars Pathfinder data for the accretion history of the terrestrial planets, Science 281, 1838-1840, 1998.
- 2661 Bickle, M. J., H. J. Chapman, J. M. Ferry, D. Rumble III, and A. E. Fallick, Fluid flow and diffusion in the Waterville limestone, south-central Maine: constraints from strontium, oxygen and carbon isotope profiles, J. Petrol. 38, 1489-1512, 1997. (No reprints available.)
- 2745 Blank, J. G., and G. H. Miller, The fate of organic compounds in cometary impacts, in Proceedings of the 21st International Symposium on Shock Waves, A. F. P. Houwing et al., eds., pp. 1205-1210, Panther Publishing, Fyshwick, Australia, 1997. (No reprints
- Boyd, F. R., The origin of cratonic peridotites: a major element approach, Int. Geol. Rev., in press.
- Boyd, F. R., D. G. Pearson, and S. A. Mertzman, Spinel-facies peridotites from the Kaapvaal root, in Proceedings of the 7th International Kimberlite Conference, in press.
- 2715 Brandes, J. A., N. Z. Boctor, G. D. Cody, B. A. Cooper, R. M. Hazen, and H. S. Yoder, Jr., Abiotic nitrogen reduction on the early Earth, Nature 395, 365-367, 1998.
- Carlson, R. W., D. G. Pearson, F. R. Boyd, S. B. Shirey, G. Irvine, A. H. Menzies, and J. J. Gurney, Re-Os systematics of lithospheric peridotites: implications for lithosphere formation and preservation, in Proceedings of the 7th International Kimberlite Conference, in press.
- 2710 Chou, I.-M., J. G. Blank, A. F. Goncharov, H. K. Mao, and R. J. Hemley, In situ observations of a highpressure phase of H₂O ice, Science 281, 809-812,
- 2732 Cody, G. D., Unraveling the mystery of coal structure with neutrons (in Japanese), Chemistry and Chemical Industry (Japan) 51, 1586-1588, 1998. (No reprints available.)
- 2700 Cody, G. D., H. Ade, S. Wirick, G. D. Mitchell, and A. Davis, Determination of chemical-structural changes in vitrinite accompanying luminescence alteration using C-NEXAFS analysis, Org. Geochem. 28, 441-455, 1998.
- Cody, G. D., and G. Sághi-Szabó, Calculation of the ¹³C NMR shielding of ether linkages of lignin derived geopolymers: constraints on the preservation of lignin primary structure, Geochim. Cosmochim. Acta,
- Cody, G. D., and P. Thiyagarajan, The macromolecular structure of coal: insight derived from small angle neutron scattering, in Materials Research Using Cold Neutrons, World Press, in press.

- 2693 Cohen, R. E., Thermal conductivity of MgO at high pressures, in Proceedings of International Conference — AIRAPT-16 and HPCJ-38 — on High Pressure Science and Technology (Rev. High Pressure Sci. Tech., Vol. 7), M. Nakahara, ed., pp. 160-162, Japan Society of High Pressure Science and Technology, Kyoto, 1998.
- 273 I Cohen, R. E., ed., First-Principles Calculations for Ferroelectrics: Fifth Williamsburg Workshop, AIP Conference Proceedings 436, American Institute of Physics, Woodbury, N.Y., 302 pp., 1998. (Available for purchase from the publisher.)
- 2744 Cohen, R. E., Mineral physics, Geotimes 43 (no. 2), 35-36, February 1998. (No reprints available.)
- 2725 Cohen, R. E., Y. Fei, R. Downs, I. I. Mazin, and D. G. Isaak, Magnetic collapse and the behavior of transition metal oxides: FeO at high pressures, in High-Pressure Materials Research, R. M. Wentzcovitch et al., eds., pp. 27-37, Symposium Proceedings Vol. 499, Materials Research Society, Warrendale, Pennsylvania, 1998. (No reprints available.)
- 2729 Cohen, R. E., L. Stixrude, and E. Wasserman, Elasticity, thermal properties, and molecular dynamics under non-empirical tight-binding, in Tight-binding Approaches to Computational Materials Science, P. E. A. Turchi, A. Gonis, and L. Colombo, eds., pp. 501-506, Symposium Proceedings Vol. 491, Materials Research Society, Warrendale, Pennsylvania, 1998. (No reprints available.)
- 2674 Cohen, R. E., and J. S. Weitz, The melting curve and premelting of MgO, in Properties of Earth and Planetary Materials at High Pressure and Temperature, M. H. Manghnani and T. Yagi, eds., pp. 185-196, American Geophysical Union, Washington, D.C., 1998.
- 2675 Conrad, P. G., The stability of almandine at high pressures and temperatures, in Properties of Earth and Planetary Materials at High Pressure and Temperature, M. H. Manghnani and T. Yagi, eds., pp. 393-400, American Geophysical Union, Washington, D.C., 1998.
- Conrad, P. G., C. S. Zha, H. K. Mao, and R. J. Hemley, The high-pressure elastic constants of pyrope, grossular and andradite, Am. Mineral., in press.
- 2735 Downs, R. T., and M. S. Somayazulu, Carbon dioxide at 1.0 GPa, Acta Cryst. C54, 897-898, 1998.
- Downs, R. T., H. Yang, R. M. Hazen, L. W. Finger, and C. T. Prewitt, Compressibility mechanisms of alkali feldspars: new data from reedmergnerite, Am. Mineral., in press.
- 2726 Duffy, T. S., G. Shen, D. L. Heinz, Y. Ma, R. J. Hemley, H. K. Mao, and A. K. Singh, Lattice strains in gold and rhenium under non-hydrostatic compression, in High-Pressure Materials Research, R. M. Wentzcovitch et al., eds., pp. 145-150, Symposium Proceedings Vol. 499, Materials Research Society, Warrendale, Pennsylvania, 1998.
- 2683 Evans, B. W., and H. Yang, Fe-Mg order-disorder in tremolite-actinolite-ferro-actinolite at ambient and high temperature, Am. Mineral. 83, 458-475, 1998. (No reprints available.)
- Farquhar, J., and D. Rumble III, Comparison of laser fluorination of olivine with KrF excimer and CO, lasers,. Geochim. Cosmochim. Acta, in press.

- Fei, Y., Effects of temperature and composition on the bulk modulus of (Mg,Fe)O, Am. Mineral., in
- Fei, Y., D. J. Frost, H. K. Mao, C. T. Prewitt, and D. Häusermann, In situ structure determination of the high-pressure phase of Fe₃O₄, Am. Mineral., in press.
- 2692 Fei, Y., C. T. Prewitt, D. J. Frost, J. B. Parise, and K. Brister, Structures of FeS polymorphs at high pressure and temperature, in Proceedings of International Conference — AIRAPT-16 and HPCJ-38 — on High Pressure Science and Technology (Rev. High Pressure Sci. Tech., Vol. 7), M. Nakahara, ed., pp. 55-58, Japan Society of High Pressure Science and Technology, Kyoto, 1998.
- Feldman, J. L., J. H. Eggert, J. De Kinder, H. K. Mao, and R. J. Hemley, Influence of order-disorder on the vibron excitations of H₂ and D₂ in ortho-para mixed crystals, J. Low Temp. Phys., in press.
- 2679 Ferry, J. M., S. S. Sorensen, and D. Rumble III, Structurally controlled fluid flow during contact metamorphism in the Ritter Range pendant, California, USA, Contrib. Mineral. Petrol. 130, 358-378, 1998.
- 2687 Finger, L. W., PROFVAL: functions to calculate powder-pattern peak profiles with axial-divergence asymmetry, J. Appl. Crystallogr. 31, 111, 1998.
- Fogel, M. L., C. Aguilar, R. Cuhel, D. J. Hollander, J. D. Willey, and H. W. Paerl, Biogeochemical response of the North Carolina coastal margin to Hurricane Gordon, Limnol. Oceanogr., in press.
- 2719 Fogel, M. L., N. Tuross, B. J. Johnson, and G. H. Miller, Biogeochemical record of ancient humans, Org. Geochem. 27, 275-287, 1997.
- 2722 Frantz, J. D., Raman spectra of potassium carbonate and bicarbonate aqueous fluids at elevated temperatures and pressures: comparison with theoretical simulations, Chem. Geol. 152, 211-225, 1998.
- 2689 Freiman, Yu. A., S. M. Tretyak, A. Jezowski, and R. J. Hemley, Broken symmetry phase transition in solid HD: a manifestation of quantum orientational melting, Fizika Nizkikh Temperatur [Low Temp. Phys.] 24 (no. 7), 683-688, 1998.
- 2743 Fricke, H. C., W. C. Clyde, J. R. O'Neil, and P. D. Gingerich, Evidence for rapid climate change in North America during the latest Paleocene thermal maximum: oxygen isotope compositions of biogenic phosphate from the Bighorn Basin (Wyoming), Earth Planet. Sci. Lett. 160, 193-208, 1998. (No reprints
- 2684 Frost, D. J., and Y. Fei, The stability of phase D at high pressure and high temperature, J. Geophys. Res. 103, 7463-7474, 1998.
- Frost, D. J., and Y. Fei, Static compression of the hydrous magnesium silicate phase D to 30 GPa at room temperature, Phys. Chem. Minerals, in press.
- Ghiorso, M. S., H. Yang, and R. M. Hazen, Thermodynamics of cation ordering in karooite (MgTi₂O₅), Am. Mineral., in press.
- 2676 Goncharov, A. F., R. J. Hemley, H. K. Mao, and J. Shu, New high-pressure excitations in parahydrogen, Phys. Rev. Lett. 80, 101-104, 1998.

Here updated through November 25, 1998. The list is regularly updated on the Geophysical Laboratory web site //www.gl.ciw.edu/GL-publications.html). Reprints of the numbered publications listed below are available, except where noted no charge from the Librarian, Geophysical Laboratory, 5251 Broad Branch Road, N.W. Washington, D.C. 20015-1305, U.S.A. (e-m. library@dtm.ciw.edu). Please give reprint number(s) when ordering.

- Goodfriend, G. A., Stable isotope records of late Quaternary paleoclimates in the eastern Mediterranean region, Quat. Sci. Rev., in press.
- 2669 Goodfriend, G. A., and K. W. Flessa, Radiocarbon reservoir ages in the Gulf of California: roles of upwelling and flow from the Colorado River, Radiocarbon 39, 139-148, 1997.
- 2740 Goodfriend, G. A., and H. B. Rollins, Recent barrier beach retreat in Georgia: dating exhumed salt marshes by aspartic acid racemization and post-bomb radiocarbon, J. Coastal Res. 14, 960-969, 1998.
- Goodfriend, G. A., and D. J. Stanley, Rapid strand plain accretion in the northeastern Nile Delta in the 9th century AD and the demise of the port of Pelusium, Geology, in press.
- 2721 Hammer, B. T., M. L. Fogel, and T. C. Hoering, Stable carbon isotope ratios of fatty acids in seagrass and redhead ducks, Chem. Geol. 152, 29-41, 1998.
- 2664 Hare, P. E., D. W. Von Endt, and J. E. Kokis, Protein and amino acid diagenesis dating, in Chronometric Dating in Archaeology, R. E. Taylor and M. J. Aitken, eds., Ch. 9, pp. 261-296, Plenum Press, New York, 1997. (No reprints available.)
- 2668 Hazen, R. M., Unanswered questions: learning what we don't know, in Vivitur Ingenio: Essays in Honor of Thelma Z. Lavine, E. Verheyen and I. Knell, eds., pp. 63-72, George Mason University, Fairfax, Virginia, 1998. (No reprints available.)
- 2707 Hazen, R. M., The stuff of life: What was life's first energy source?, Planetary Report 18 (no. 4), 16-17, 1998. (No reprints available.)
- Hazen, R. M., The Diamond Makers, Cambridge University Press, in press.
- 2733 Hazen, R. M., and M. Singer, Warum schwarze Löcher nicht schwarz sind: offene Fragen aus den Grenzbereichen der Wissenschaft, Deuticke, Vienna and Munich, 360 pp., 1998. (Available for purchase from the publisher.)
- 2708 Hazen, R. M., and J. Trefil, Alfabetismo científico, in La popularización de la ciencia y la technología, E. Martínez and J. Flores, eds., pp. 46-50, Fondo de Cultura Económica, Mexico, 1997. (No reprints available.)
- 2712 Hemley, R. J., Superconductivity in a grain of salt, Science 281, 1296-1297, 1998.
- 2717 Hemley, R. J., Matter, Properties at high pressure and temperature, in Sciences of the Earth: An Encyclopedia of Events, People, and Phenomena, G. A. Good, ed., pp. 523-535, Garland Publishing, New York, 1998. (No reprints available.)
- 2709 Hemley, R. J., and N. W. Ashcroft, The revealing role of pressure in the condensed matter sciences, Phys. Today 51 (no. 8), 26-32, 1998.
- 2713 Hemley, R. J., A. F. Goncharov, R. Lu, V. V. Struzhkin, M. Li, and H. K. Mao, High-pressure synchrotron infrared spectroscopy at the National Synchrotron Light Source, Nuovo Cimento D 20, 539-551, 1998.
- 2666 Hemley, R. J., A. F. Goncharov, H. K. Mao, E. Karmon, and J. H. Eggert, Spectroscopic studies of p-H₂ to above 200 GPa, J. Low Temp. Phys. 110, 75-88, 1998,

- 2685 Hemley, R. J., and H. K. Mao, Static compression experiments on low-Z planetary materials, in Properties of Earth and Planetary Materials at High Pressure and Temperature, M. H. Manghnani and T. Yagi, eds., pp. 173-183, American Geophysical Union, Washington, D.C., 1998.
- Hemley, R. J., M. S. Somayazulu, A. F. Goncharov, and H. K. Mao, High-pressure Raman spectroscopy of Ar-H, and CH₄-H, van der Waals compounds, Asian J. Phys., in press.
- Hirose, K., Y. Fei, Y. Ma, and H. Mao, Fate of subducted basaltic crust in the lower mantle, Nature, in press.
- Ilchik, R. P., and D. Rumble III, Sulfur, carbon and oxygen systematics during diagenesis and fluid infiltration in the Creede Caldera, Colorado, in Preliminary Scientific Results of the Creede Caldera Continental Scientific Drilling Program, P. M. Bethke, ed., Ch. II, U.S. Geol. Surv. Open-File Report 94-260, in
- 2734 Irvine, T. N., J. C. Ø. Andersen, and C. K. Brooks, Included blocks (and blocks within blocks) in the Skaergaard intrusion: geologic relations and the origins of rhythmic modally graded layers, Geol. Soc. Am. Bull. 110, 1398-1447, 1998. (No reprints available.)
- 2680 Ita, J., and R. E. Cohen, Diffusion in MgO at high pressure: implications for lower mantle rheology, Geophys. Res. Lett. 25, 1095-1098, 1998.
- 2720 Johnson, B. J., M. L. Fogel, and G. H. Miller, Stable isotopes in modern ostrich eggshell: a calibration for paleoenvironmental applications in semi-arid regions of southern Africa, Geochim. Cosmochim. Acta 62, 2451-2462, 1998.
- 2665 Johnson, B. J., G. H. Miller, M. L. Fogel, and P. B. Beaumont, The determination of late Quaternary paleoenvironments at Equus Cave, South Africa, using stable isotopes and amino acid racemization in ostrich eggshell, Palaeogeogr. Palaeoclimatol. Palaeoecol. 136, 121-137, 1997.
- 2716 Kowalewski, M., G. A. Goodfriend, and K. W. Flessa, High-resolution estimates of temporal mixing within shell beds: the evils and virtues of time-averaging, Paleobiology 24, 287-304, 1998. (No reprints available.)
- 2738 Lin, C. M., D. S. Chuu, W. C. Chou, J. Xu, E. Huang, J. Z. Hu, and J. H. Pei, Phase transitions of Zn_{0.84}Fe_{0.16}Se under high-pressure, Solid State Commun. 107, 217-221, 1998. (No reprints available.)
- 2739 Lin, C. M., D. S. Chuu, J. Xu, E. Huang, W. C. Chou, J. Z. Hu, and J. H. Pei, High-pressure phase transitions in Zn, M,Se (M=Cd, Fe, and Mn), Phys. Rev. B 58, 16-19, 1998. (No reprints available.)
- 2742 Linton, J., A. Navrotsky, and Y. Fei, The thermodynamics of ordered perovskites on the CaTiO₃-FeTiO₃ join, Phys. Chem. Minerals 25, 591-596, 1998.
- 2681 Mao, H. K., R. J. Hemley, and A. L. Mao, Diamond-cell research with synchrotron radiation, in Advances in High Pressure Research in Condensed Matter, S. K. Sikka, S. C. Gupta, and B. K. Godwal, eds., pp. 12-19, National Institute of Science Communication, New Delhi, India, 1997.

- 2663 Mao, H. K., G. Shen, and R. J. Hemley, Multivariate dependence of Fe-Mg partitioning in the lower mantle, Science 278, 2098-2100, 1997.
- 2672 Mao, H. K., G. Shen, R. J. Hemley, and T. S. Duffy, X-ray diffraction with a double hot-plate laserheated diamond cell, in Properties of Earth and Planetary Materials at High Pressure and Temperature, M. H. Manghnani and T. Yagi, eds., pp. 27-34, American Geophysical Union, Washington, D.C.,
- Mao, H. K., J. Shu, R. J. Hemley, B. Li, and A. K. Singh, Elasticity and rheology of iron above 220 GPa and the nature of the Earth's inner core, Nature, in
- 2686 Mazin, I. I., Y. Fei, R. Downs, and R. Cohen, Possible polytypism in FeO at high pressures, Am. Mineral. 83, 451-457, 1998.
- Merkel, S., R. J. Hemley, and H. K. Mao, Finite element modeling of diamond deformation at multimegabar pressures, Appl. Phys. Lett., in press.
- Minarik, W. G., Complications to carbonate melt mobility due to the presence of an immiscible silicate melt, J. Petrol., in press.
- Murillo de Nava, J., D. S. Gorsline, G. A. Goodfriend, V. K. Vlasov, and R. Cruz-Orozco, Evidence of Holocene climatic changes from aeolian deposits in Baja California Sur, México, Quatemary International, in press.
- 2699 Mysen, B., Transport and configurational properties of silicate melts: relationship to melt structure at magmatic temperatures, Phys. Earth Planet. Inter. 107, 23-32, 1998.
- 2702 Mysen, B. O., Interaction between aqueous fluid and silicate melt in the pressure and temperatures regime of the Earth's crust and upper mantle, Neues Jahrb. Mineral. Abh. 172, 227-244, 1998.
- 2746 Mysen, B. O., Phosphorous solubility mechanisms in haplogranitic aluminosilicate glass and melt: effect of temperature and aluminum content, Contrib. Mineral. Petrol. 133, 38-50, 1998.
- Mysen, B., Silicate melts and glasses: the influence of temperature and composition on the structural behavior of anionic units, in K. Yagi 80th Birthday Commemoration Volume, A. Gupta, ed., Indian Academy of Sciences, in press.
- Mysen, B. O., Structure and properties of magmatic liquids: from haplobasalt to haploandesite, Geochim. Cosmochim. Acta, in press.
- Mysen, B. O., F. Holtz, M. Pichavant, J.-M. Beny, and J.-M. Montel, The effect of temperature and bulk composition on the solution mechanism of phosphorus in peraluminous haplogranitic magma, Am. Mineral., in press.
- 2711 Mysen, B. O., D. Virgo, R. K. Popp, and C. M. Bertka, The role of H₂O in Martian magmatic systems, Am. Mineral. 83, 942-946, 1998.
- Paerl, H. W., J. D. Willey, M. Go, B. L. Peierls, J. L. Pinckney, and M. L. Fogel, Rainfall stimulation of primary production in western Atlantic Ocean waters: roles of different nitrogen sources and co-limiting nutrients, Mar. Ecol. Prog. Ser., in press.

2691 Prewitt, C. T., T. Ko, G. Shen, and J. D. FitzGerald, Role of twinning in perovskite - lithium niobate phase transitions, in Proceedings of International Conference — AIRAPT-16 and HPCJ-38on High Pressure Science and Technology (Rev. High Pressure Sci. Tech., Vol. 7), M. Nakahara, ed., pp. 40-43, Japan Society of High Pressure Science and Technology, Kyoto, 1998.

Geophysical Laboratory Bibliography

- 2695 Qadri, S. B., E. F. Skelton, A. W. Webb, J. Z. Hu, J. Kennedy, and C. Kim, Phase transition in Cd, Zn,Te (0≤x≤0.55), in Proceedings of International Conference — AIRAPT-16 and HPCJ-38 — on High Pressure Science and Technology (Rev. High Pressure Sci. Tech., Vol. 7), M. Nakahara, ed., pp. 319-321, Japan Society of High Pressure Science and Technology,
- 2696 Qadri, S. B., E. F. Skelton, J. Yang, B. R. Rama, and J. Z. Hu, Pressure induced structural transitions in nanometer size particles of PbS, in Proceedings of International Conference — AIRAPT-16 and HPCJ-38 on High Pressure Science and Technology (Rev. High Pressure Sci. Tech., Vol. 7), M. Nakahara, ed., pp. 325-326, Japan Society of High Pressure Science and Technology, Kyoto, 1998.
- 2705 Richet, P., B. O. Mysen, and J. Ingrin, High-temperature X-ray diffraction and Raman spectroscopy of diopside and pseudowollastonite, Phys. Chem. Minerals 25, 401-414, 1998.
- Rumble, D., Stable isotope geochemistry of ultrahigh-pressure rocks, in When Continents Collide: Geodynamics and Geochemistry of Ultrahigh-Pressure Rocks, B. R. Hacker and J. G. Liou, eds., Kluwer Academic Publishers, Dordrecht, in press.
- 2660 Rumble, D., III., J. Farquhar, E. D. Young, and C. P. Christensen, In situ oxygen isotope analysis with an excimer laser using F₂ and BrF₅ reagents and O₂ gas as analyte, Geochim. Cosmochim. Acta 61, 4229-4234,
- Rumble, D., and Z. D. Sharp, Laser microanalysis of silicates for 180/170/160 and of carbonates for 18O/16O and 13C/12C, in Society of Economic Geologists, Short Course Notes, in press.
- Rumble, D., and T. F. Yui, The Qinglongshan oxygen and hydrogen isotope anomaly near Donghai in Jiangsu Province, China, Geochim. Cosmochim. Acta,
- 2741 Russell, S. S., T. J. McCoy, E. Jarosewich, and R. D. Ash, The Burnwell, Kentucky, low iron oxide chondrite fall: description, classification and origin, Meteoritics Planet. Sci. 33, 853-856, 1998.
- 2688 Sághi-Szabó, G., and R. E. Cohen, First principles study of piezoelectricity in PbTiO₃, Phys. Rev. Lett. 80, 4321-4324, 1998.
- 2723 Sághi-Szabó, G., R. E. Cohen, and H. Krakauer, First principles study of piezoelectricity in tetragonal PbTiO₃, Ferroelectrics 206/207, 1-10, 1998.
- 2730 Sághi-Szabó, G., R. E. Cohen, and H. Krakauer, First-principles study of piezoelectricity in tetragonal PbTiO₃ and PbZr₁₀Ti₁₀O₃, in First-Principles Calculations for Ferroelectrics: Fifth Williamsburg Workshop, R. E. Cohen, ed., pp. 43-52, AIP Conference Proceedings 436, American Institute of Physics, Woodbury, N.Y.,

- 2706 Schmidt, M. W., L. W. Finger, R. J. Angel, and R. E. Dinnebier, Synthesis, crystal structure, and phase relations of AlSiO₃OH, a high-pressure hydrous phase, Am. Mineral. 83, 881-888, 1998.
- 2667 Shen, G., H. K. Mao, R. J. Hemley, T. S. Duffy, and M. L. Rivers, Melting and crystal structure of iron at high pressures and temperatures, Geophys. Res. Lett. 25, 373-376, 1998.
- 2698 Shieh, S. R., H. K. Mao, R. J. Hemley, and L. C. Ming, Decomposition of phase D in the lower mantle and the fate of dense hydrous silicates in subducting slabs, Earth Planet. Sci. Lett. 159, 13-23, 1998.
- 2703 Shu, J., H. K. Mao, J. Hu, Y. Fei, and R. J. Hemley, Single-crystal X-ray diffraction of wüstite to 30 GPa hydrostatic pressure, Neues Jahrb. Mineral. Abh. 172, 309-323, 1998.
- 2690 Singh, A. K., C. Balasingh, H. K. Mao, R. J. Hemley, and J. Shu, Analysis of lattice strains measured under nonhydrostatic pressure, J. Appl. Phys. 83, 7567-7575, 1998.
- 2694 Singh, A. K., C. Balasingh, H. K. Mao, J. Shu, and R. J. Hemley, Interpretation of the lattice-strains measured under non-hydrostatic pressure, in Proceedings of International Conference — AIRAPT-16 and HPCJ-38 on High Pressure Science and Technology (Rev. High Pressure Sci. Tech., Vol. 7), M. Nakahara, ed., pp. 205-210, Japan Society of High Pressure Science and Technology, Kyoto, 1998.
- 2677 Singh, A. K., H. K. Mao, J. Shu, and R. J. Hemley, Estimation of single-crystal elastic moduli from polycrystalline x-ray diffraction at high pressure: application to FeO and iron, Phys. Rev. Lett. 80, 2157-2160, 1998.
- Skelton, E. F., P. L. Hagans, S. B. Qadri, D. D. Dominguez, A. C. Ehrlich, and J. Z. Hu, In situ monitoring of crystallographic changes in Pd induced by diffusion of D, Phys. Rev. B, in press.
- 2728 Somayazulu, M. S., R. J. Hemley, A. F. Goncharov, H. K. Mao, and L. W. Finger, High-pressure compounds in the methane-hydrogen system: Xray, infrared and Raman studies on CH₄(H₂)₂, Eur. J. Solid State Inorg. Chem. 34, 705-713, 1997.
- 2724 Stixrude, L., E. Wasserman, and R. E. Cohen, First-principles investigations of solid iron at high pressure and implications for the Earth's inner core, in Properties of Earth and Planetary Materials at High Pressure and Temperature, M. H. Manghnani and T. Yagi, eds., pp. 159-171, American Geophysical Union, Washington, D.C., 1998.
- 2662 Struzhkin, V. V., R. J. Hemley, H. K. Mao, and Y. Timofeev, Superconductivity at 10-17 K in compressed sulfur, Nature 390, 382-384, 1997.
- 2678 Teter, D. M., R. J. Hemley, G. Kresse, and J. Hafner, High pressure polymorphism in silica, *Phys. Rev. Lett.* 80, 2145-2148, 1998.
- Velinsky, D. J., and M. L. Fogel, Cycling of dissolved and particulate nitrogen and carbon in the Framvaren Fjord, Norway: stable isotopic variations, Mar. Chem., in press.
- 2727 Wentzcovich, R. M., R. J. Hemley, W. J. Nellis, and P. Y. Yu, eds., High-Pressure Materials Research, Symposium Proceedings Vol. 499, Materials Research Society, Warrendale, Pennsylvania, 1998. (Available for purchase from the publisher.)

- Yang, H., L. W. Finger, P. G. Conrad, C. T. Prewitt, and R. M. Hazen, A new pyroxene structure type observed at high pressure: single-crystal X-ray diffraction and Raman spectroscopic studies of the Pbcn-P2, cn phase transition in protopyroxene, Am. Mineral., in press.
- 2704 Yang, H., and R. M. Hazen, Crystal chemistry of cation order-disorder in pseudobrookite-type MgTi₂O₅, J. Solid State Chem. 138, 238-244, 1998.
- Yang, H., and R. M. Hazen, Comparative highpressure crystal chemistry of karooite, MgTi₂O₅, with different ordering states, Am. Mineral., in press.
- 2670 Yang, H., R. M. Hazen, L. W. Finger, C. T. Prewitt, and R. T. Downs, Compressibility and crystal structure of sillimanite, Al₂SiO₅, at high pressure, *Phys.* Chem. Minerals 25, 39-47, 1997.
- 2671 Yang, H., R. M. Hazen, C. T. Prewitt, L. W. Finger, R. Lu, and R. J. Hemley, High-pressure singlecrystal X-ray diffraction and infrared spectroscopic studies of the C2/m-P2,/m phase transition in cummingtonite, Am. Mineral. 83, 288-299, 1998.
- 2718 Yoder, H. S., Jr., Petrology, in Sciences of the Earth: An Encyclopedia of Events, People, and Phenomena, G. A. Good, ed., pp. 675-682, Garland Publishing, New York, 1998. (No reprints available.)
- 2736 Yoder, H. S., Jr., Italian volcanology: Geophysical Laboratory contributions, 1905-1965, in Volcanoes and History: Proceedings of the 20th INHI-GEO Symposium, N. Morello, ed., pp. 707-734, Glauco Brigati, Genova, Italy, 1998. (No reprints available.)
- Young, E. D., M. L. Fogel, D. Rumble III, and T. C. Hoering, Isotope-ratio-monitoring of O_2 for microanalysis of 180/160 and 170/160 in geological materials, Geochim. Cosmochim. Acta, in press.
- Young, E. D., H. Nagahara, B. O. Mysen, and D. M. Audet, Non-Rayleigh oxygen isotope fractionation by mineral evaporation: theory and experiments in the system SiO₂, Geochim. Cosmochim. Acta, in
- 2701 Zha, C. S., T. S. Duffy, R. T. Downs, H. K. Mao, and R. J. Hemley, Brillouin scattering and x-ray diffraction of San Carlos olivine: direct pressure determination to 32 GPa, Earth Planet. Sci. Lett. 159, 25-33,
- 2673 Zha, C. S., T. S. Duffy, R. T. Downs, H. K. Mao, R. J. Hemley, and D. J. Weidner, Single-crystal elasticity of the α and β of Mg₂SiO₄ polymorphs at high pressure, in Properties of Earth and Planetary Materials at High Pressure and Temperature, M. H. Manghnani and T. Yagi, eds., pp. 9-16, American Geophysical Union, Washington, D.C., 1998.
- 2697 Zha, C. S., H. K. Mao, R. J. Hemley, and T. S. Duffy, Recent progress in high-pressure Brillouin scattering: olivine and ice, in Proceedings of International Conference — AIRAPT-16 and HPCJ-38 — on High Pressure Science and Technology (Rev. High Pressure Sci. Tech., Vol. 7), M. Nakahara, ed., pp. 739-741, Japan Society of High Pressure Science and Technology, Kyoto, 1998.
- 2737 Zhang, R. Y., D. Rumble III, J. G. Liou, and Q. C. Wang, Low $\delta^{\text{\tiny IS}}$ O, ultrahigh-P gamet-bearing mafic and ultramafic rocks from Dabie Shan, China, Chem. Geol. 150, 161-170, 1998.



CARNEGIE SCIENCE FOR THE CITY: PREPARING FOR THE SECOND CENTURY

In September 1997, the Carnegie Building was emptied of its inhabitants. and renovation began. For nine months, the 90-year-old building withstood an onslaught of engineers; contractors, and hazardous waste abatement specialists. Finally, in May 1998, the work was finished. While the building looked essentially the same (save for new classrooms on the ground floor and a general cleaning and refurbishing throughout), there was in place a sophisticated heating-air conditioning system, updated telecommunications networks, and new electrical wiring and plumbing. In addition, the structure was brought up to fire and safety code and made compliant with the Americans with Disabilities Act. The murals of the auditorium had been cleaned and a new audiovisual system installed.

The renovation was the first that the historic building (declared a National Historic Landmark in 1965) had ever received. A major motivation behind it was to update the space for the education activities held inside its walls. Those include First Light, the Saturday science school for city youngsters; the Carnegie Academy for Science Education, the summer science-teaching institute for local elementary school teachers; and the Capital Science Lectures, a series of free public lectures by renowned scientists worldwide.

Cleaned, polished, and shining, the building is now prepared for its second century of service to the Carnegie Institution, and to the children, teachers and citizens of the nation's capital.

Top: A view of the rotunda. New lighting was added to highlight the architechural features.

Middle: Root Hall, with new seating, cleaned murals, and updated audiovisual equipment.

Bottom: CASE teachers using new computer facilities in the Cafritz Science Resource Center.

Carnegie Administrative Personnel

Lloyd Allen, Building Maintenance Specialist

Sharon Bassin, Secretary to the President

Sherrill Berger, Research Assistant, External Affairs

Gloria Brienza, Budget and Management Analysis Manager

Don A. Brooks, Building Maintenance Specialist

Cady Canapp, Human Resources and Insurance Manager

Margaret Charles, Secretary

Patricia Craig, Editor and Publications Officer

Karin Dasuki, Financial Accountant

Sonja DeCarlo, Grants and Operations Manager

Susanne Garvey, Director of External Affairs

Ann Keyes, Payroll Coordinator

Jennifer King, Assistant Editor²

Jeffrey Lightfield, Financial Accountant³

John Lively, Director of Administration and Finance

Trong Nguyen, Financial Accountant

Catherine Piez, Endowment Manager

Arnold Pryor, Facilities and Services Supervisor

Michelle Robinson, Housekeeper^s

Maxine F. Singer, President

Susan Smith, Administrative Secretary

John Strom, Facilities Coordinator

Kris Sundback, Financial Manager

Vickie Tucker, Administrative Coordinator/Accounts Payable

Susan Vasquez, Assistant to the President

Melanie Wade, Financial Accountant⁶

Yulonda White, Human Resources & Insurance Records Coordinator

Catherine Whittenburg, Assistant Editor³

Jacqueline Williams, Assistant to Manager/Human Resources & Insurance

From June 22, 1998

²To July 25, 1997

³To August 15, 1997

From October 15, 1997

⁵ From June 29, 1998

⁶To May 22, 1998

⁷From August 12, 1997

Carnegie Academy for Science Education

Michael Charles, CASE Intem¹

Inés L. Cifuentes, CASE Director

Carolyn Dickie, Mentor Teacher²

Linda Feinberg, CASE Administrator and Editor

Kim Fridie, Mentor Teacher²

Maritsa George, Mentor Teacher

Jacqueline Goodloe, Mentor Teacher

Alida James, Mentor Teacher

Charles James, CASE and First Light Director

Jacqueline Lee, Mentor Teacher³

Jennifer Lee, CASE Intem³

Sandra Norried, Mentor Teacher

Martin Murray, Mentor Teacher³

Victor Pineiro, CASE Intem²

Gwendolyn Robinson, Mentor Teacher³

Tracy Robinson, Mentor Teacher²

Daniel Robison, CASE Intem²

Jennifer Seligmann, CASE Intem²

Ollie Smith, Mentor Teacher²

Gregory Taylor, Mentor Teacher and First Light Assistant

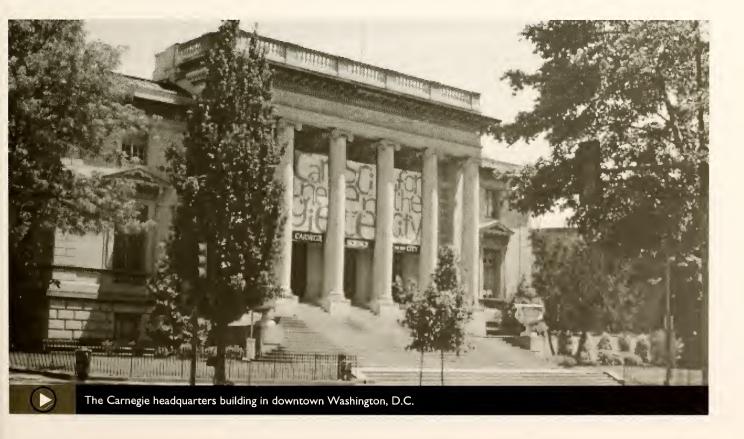
Jerome Thornton, Mentor Teacher

Kalin Tobler, Mentor Teacher²

Joan Turner, Mentor Teacher³

Sue P. White, Mathematics Coordinator

Laurie Young, Mentor Teacher



 $^{^{\}rm I}$ From July 1, 1997 to September 1, 1997, and from June 20, 1998

²From June 20, 1998

³From July 1, 1997 to September 1, 1997

The Capital Sciences Lectures are sponsored by the institution with substantial support from the Johnson & Johnson Family of Companies, Human Genome Sciences, Inc., and the Schering-Plough Corporation, Due to renovation of the Carnegie Institution's building at 16th and P Streets, the 1997-1998 lectures were held at the nearby District of Columbia Jewish Community Center, located on the corner of 16th and Q Streets. The lectures are free and open to the public. Speakers also meet informally with groups of high school students. During the 1997-1998 year, the following lectures were given:



CAPITAL SCIENCE LECTURES

It Takes an Ocean: Submarine Volcanic Activity and Life in Our Solar System, by John R. Delaney (School of Oceanography, University of Washington), October 14, 1997

Molecular Conversations of Plants and Bacteria, by Sharon R. Long (Department of Biological Sciences, Stanford University and Howard Hughes Medical Institute), November 18, 1997

Exploring the Giant Planets with the Hubble Space Telescope, by Heidi B. Hammel (Department of Earth, Atmospheric, and Planetary Sciences, MIT), January 20, 1998

Genetics of Breast Cancer: Families and Clues to New Therapies, by Mary-Claire King (Department of Medicine and Genetics, University of Washington), February 10, 1998

Probing the Depths of Geology, by Paul G. Silver (Department of Terrestrial Magnetism, Carnegie Institution), March 17, 1998

Barbara McClintock's Legacy: The Jokers in Genomes, by Maxine F. Singer (President, Carnegie Institution of Washington), April 14, 1998

Diamond Windows on a New Chemistry, by Russell J. Hemley (Geophysical Laboratory, Carnegie Institution), May 12, 1998

Publications of the President

Singer, M. F., Betting on Research, in *Nurturing Creativity in Research: Ideas as the Foundations of Innovation*, P. M. Shearmur et al., eds., pp. 150-153, Research School of Biological Sciences, Institute of Advanced Studies, The Australian National University, Canberra, 1997.

Singer, M. F., D.C. Public Schools: Train the Teachers, *The Washington Post*, OpEd page, February 22, 1997.

Singer, M. F., On the Future of America's Scientific Enterprise, in *Universities and Their Leadership*, William G. Bowen and Harold T. Shapiro, eds., pp. 251-258, Princeton University Press, Princeton, NJ, 1998.

Clements, Andrew P., and M. F. Singer, The human LINE-1 reverse transcriptase: effects of deletions outside the common reverse transcriptase domain, *Nucl. Acids Res. 26*, 3528-3535, 1998.



for the year ended June 30, 1998

Financial Profile

Reader's Note: In this section, any discussion of spending levels or endowment amounts are on a cash or cash-equivalent basis. Therefore, the funding amounts presented do not reflect the impact of capitalization, depreciation, or other non-cash amounts.

The primary source of support for Carnegie Institution of Washington's activities is its endowment. This results in a fundamental independence in the conduct of the institution's scientific programs that is planned to continue into the future.

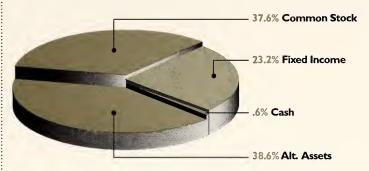
At June 30, 1998, the endowment was valued at approximately \$423.3 million. Carnegie's endowment is allocated among a broad spectrum of asset classes. This includes fixed-income instruments (bonds), equities (stocks), arbitrage and distressed securities, real estate partnerships, private equity, an oil and gas partnership, and a hedge fund. The institution relies upon external managers and partnerships to conduct these investments and activities, and it employs a commercial bank to maintain custody.

For the fiscal year ended on June 30, 1998, Carnegie's endowment had a total return (net of management fees) of 16.3%. The annualized fiveyear return for the endowment was 13.7%.

The following chart shows the allocation of the institution's endowment among the asset classes it uses as of June 30, 1998:

	Target Allocation	Actual Allocation
Common Stock	40%	37.6%
Alternative Assets	35%	38.6%
Fixed Income	25%	23.2%
Cash	0%	0.6%

Actual Asset Allocation



Carnegie's objective is to maintain the long-term spending power of its endowment. The result is a budgeting methodology that provides for:

- averaging the total market value of the endowment for the three most recent fiscal years, and
- developing a budget that spends at a set percentage (spending rate) of this three-year market average.

During the 1990s, this budgeted spending rate has been declining in a phased reduction, moving towards an informal goal of 4.5%. For the 1998-1999 fiscal year, the rate is budgeted at 5.5%. While Carnegie has been reducing this budgeted rate by between 5 and 10 basis points a year, there has also been continuing, significant growth in the size of the endowment. The result has been that, for the fiscal year ended in June 1998, the actual spending rate (the ratio of annual spending from the endowment to actual endowment value at the conclusion of the fiscal year in which the spending took place) declined to 3.87%.

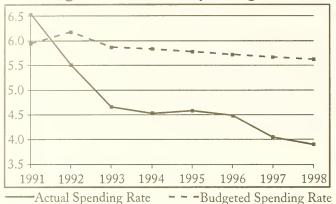
The following table compares the planned versus the actual spending rates, as well as the market value of the endowment from 1991-1992 to the most recently concluded fiscal year, 1997-1998.

Endowment Spending Over Seven Years

(Dollars in Millions) FY	91-92	92-93	93-94	94-95	95-96	96-97	97-98
Endowment Spending	\$13.5	\$12.5	\$12.4	\$13.9	\$15.1	\$15.5	\$16.4
Actual Market Value at June 30	\$246.6	\$270.4	\$275.5	\$304.5	\$338.0	\$382.9	\$423.3
Actual Spending as % of Market Value	5.49%	4.63%	4.51%	4.57%	4.48%	4.05%	3.87%
Planned Spending Rate in Budget	6.16%	5.86%	5.81%	5.76%	5.71%	5.66%	5.61%

UNAUDITED

Budgeted and Actual Spending Rates



Within Carnegie's endowment, there are a number of "Funds" that provide support either in a general way or in a targeted way, with a specific, defined purpose. The largest of these is the Andrew Carnegie Fund, begun with the original gift of \$10 million. Mr. Carnegie later made additional gifts totaling another \$12 million during his lifetime. This fund is now valued at \$342 million.

Market value of the Principal Funds Within Carnegie's Endowment

Andrew Carnegie	\$341,997,603
Capital Campaign	26,690,920
Anonymous	10,468,951
Astronomy Funds	12,324,403
Mellon Matching	9,264,723
Anonymous Matching	6,687,585
Carnegie Futures	5,873,846
Wood	4,591,855
Golden	2,729,709
Bowen	2,178,869
Colbum	1,822,838
McClintock Fund	1,375,436
Special Instrumentation	963,320
Bush Bequest	859,329
Moseley Astronomy	725,269
Special Opportunities	635,279
Roberts	374,025
Lundmark	295,281
Starr Fellowship	671,693
Morgenroth	216,379
Hollaender	201,056
Bush	120,409
Moseley	131,034
Forbush	122,304
Green	85,589
Hale	81,415
Harkavy	76,746
Hearst Education Fund	231,730
Other	5,144

Financial Statements and Schedule

Independent Auditors' Report

To the Auditing Committee of the Carnegie Institution of Washington:

We have audited the accompanying statements of financial position of the Carnegie Institution of Washington (Carnegie) as of June 30, 1998 and 1997, and the related statements of activities and cash flows for the years then ended. These financial statements are the responsibility of the Institution's management. Our responsibility is to express an opinion on these financial statements based on our audits.

We conducted our audits in accordance with generally accepted auditing standards. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation. We believe that our audits provide a reasonable basis for our opinion.

In our opinion, the financial statements referred to above present fairly, in all material respects, the financial position of the Carnegie Institution of Washington as of June 30, 1998 and 1997, and its changes in net assets and its cash flows for the years then ended, in conformity with generally accepted accounting principles.

Our audits were made for the purpose of forming an opinion on the basic financial statements taken as a whole. The supplementary information included in Schedule I is presented for purposes of additional analysis and is not a required part of the basic financial statements. Such information has been subjected to the auditing procedures applied in the audit of the basic financial statements and, in our opinion, is fairly presented in all material respects in relation to the basic financial statements taken as a whole

KPMA Peat Marwick LLP October 30, 1998

Total

Statements of Financial Position June 30, 1998 and 1997

Assets		1997
Cash and cash equivalents	\$ 147,343	2,759,057
Accrued investment income	665,437	477,140
Contributions receivable (note 2)	2,414,271	3,773,587
Accounts receivable and other assets	2,573,029	2,007,377
Bond proceeds held by trustee (note 6)	7,162,230	11,159,876
Investments (note 3)	431,802,740	380,747,708
Construction in progress (notes 4 and 5)	40,642,497	28,737,444
Property and equipment, net (note 4)	41,607,411	37,880,114
	\$ 527,014,958	467,542,303
Liabilities and Net Assets		
Accounts payable and accrued expenses	\$ 2,409,330	2,068,094
Deferred revenue (note 5)	12,108,046	1,149,050
Broker payable (note 3)	2,171,665	0
Bonds payable (note 6)	34,806,460	34,769,596
Accrued postretirement benefits (note 7)	9,836,437	9,236,983
Total liabilities	61,331,938	47,223,723
Net assets (note 8):		
Unrestricted:		
Board designated:		
Invested in fixed assets, net	35,335,402	31,847,962
Designated for managed investments	369,733,863	331,472,827
Undesignated	10,489,238	6,728,893
	415,558,503	370,049,682
Temporarily restricted	14,172,427	15,586,090
Permanently restricted	35,952,090	34,682,808
Total net assets	465,683,020	420,318,580
Commitments and contingencies (notes 9, 10, and 11)		
Total liabilities and net assets	\$527,014,958	467,542,303

See accompanying notes to financial statements.

Statements of Activities

Years ended June 30, 1998 and 1997

1998

1997

		The second secon	William to the second of the second	A a transport of the control of the	The state of the s		A CONTRACTOR OF THE CONTRACTOR	and an included the second
	Unrestricted	Temporarily restricted	Permanently restricted	Total	Unrestricted	Temporarily restricted	Permanently restricted	Total
Revenues and support:				Company of the Company	- 19 80 BA (10 1) (10 11)		, s — promise — f i sign	e transcription (Section Constitution Consti
Grants and contracts	\$ 11,259,930	0	0	#11,259,930°	10,340,760		5 40°	10,340,760
Contributions and gifts	709,030	3,894,584	1,144,309	5,747,923	740,031	6,058,154	2,220,044	9,018,229
Net gain (loss) on disposal	·	3,071,001	1,111,502	3,717,723	7 10,031	0,050,151	~ Z ₁ ZZO ₁ O 1 1	7,010,227
of property	(90,224)	0	0	(90,224)	(60,694)	o de la companya de	0.	(60,694)
Other income	720,656	0	0	720,656	623,102	0	0	623,102
and the state of the section of the		ether thanks their systemistration common an			Athrill Greenward and Silver	ti di Sistema di Salahan da Salah Salahan da Salahan da S	The second secon	enniky nich a jehnhyes (************************************
Net external revenue	12,599,392	3,894,584	1,144,309	17,638,285	11,643,199	6,058,154	2,220,044	19,921,397
Investment income (note 3)	54,982,546	4,016,507	124,973	59,124,026	53,009,113	3,387,347	118,502	56,514,962
Net assets released from						r fan defrije filt op als saalig. Gestaan		
restrictions (note 8)	9,324,754	(9,324,754)	O	O	3,346,896	(3,346,896)		O i
T								
Total revenues, gains, and	74.004.403	(1.412.442)	1240,202	77777	47,000,000	4,000,405	2 220 5 44	74 424 250
other support	76,906,692	(1,413,663)	1,269,282	76,762,311	67,999,208	6,098,605	2,338,546	76,436,359
Program and supporting serv	ices expenses					Albinia in		
Terrestrial Magnetism	6,221,701	0	0	6,221,701	5,481,263	0	0	5,481,263
Observatories	5,799,559	0	0	5,799,559	5,595,168	0	0	5,595,168
Geophysical Laboratory	6,283,859	0	0.	6,283,859	5,648,244	0	lo lo	5,648,244
Embryology	5,163,256	0	0	5,163,256	5,097,677	0	0	5,097,677
Plant Biology	4,562,436	0	9/4/// 0	4,562,436	4,450,109	0	0	4,450,109
Other Programs	1,050,946	0		1,050,946	943,838	0	0	943,838
Administrative and								
general expenses	2,316,114	12000	0	2,316,114	2,565,202	0	0	2,565,202
	21.207.071			21207071	20.701.501	^		20.701.501
Total expenses	31,397,871	0	0	31,397,871	29,781,501	0	0	29,781,501
Increase (decrease) in		Jan Hansinia			1.44			
net assets	45,508,821	(1,413,663)	1,269,282	45,364,440	38,217,707	6,098,605	2,338,546	46,654,858
net assets	13,300,021	(1,113,003)	1,207,202	13,301,110	30,217,707	0,070,003	2,330,310	10,00 1,000
Net assets at the beginning								
of the year	370,049,682	15,586,090	34,682,808	420,318,580	331,831,975	9,487,485	32,344,262	373,663,722
and anti-demail a little of the control of the cont	are a restricted a small cut of the case are a small	and the second of the second o	and the state of the second of		and the second seco			and the first of the control of the state of
Net assets at the end								
of the year	\$ 415,558,503	14,172,427	35,952,090	465,683,020	370,049,682	15,586,090	34,682,808	420,318,580
mercant hard and any colour of and attended and any and and any and all the second and	Control Startegaster and assessment of the control	San and and other more replaced to the sand and	Seat of the second track	The Committee of the State of the Committee of the Commit	William opens to the street of the self-self-self-self-self-self-self-self-	more and management at the got to	mind and respond the section of	The said of the said of the said of the said of the

See accompanying notes to financial statements.

Statements of Cash Flows

Years ended June 30, 1998 and 1997

1998	1997
\$ 45,364,440	46,654,858
2 400 204	2.450.025
	2,458,035
	(45,740,779) 60,694
\$8.33349 TT	36,865
	(1,499,164)
(1,125), (1)	(1,1,2,1101)
793,664	(939,112)
(169,530)	368,324
341,236	(451,265)
	(98,279)
599,454	576,112
(A)	(E 222 E (E)
(2,/16,/82)	(5,233,565)
8,769,555	(3,807,276)
	And the second of the second o
3 997 646	3,872,682
	(2,116,260)
	(5,324,147)
	(,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
(427,075,566)	(436,911,531)
427,190,728	441,715,012
and the second s	
(14,098,051)	1,235,756
1,269,282	2,497,544
1,447,500	2,736,021
A second control of the second control of th	5.000.5.45
2,/16,/82	5,233,565
(2,611,714)	2,662,045
2.750.057	07.012
2,/59,05/	97,012
\$147,343	2,759,057
\$ 1,568,792	1,622,971
	\$ 45,364,440 2,488,284 (47,591,512) 90,224 36,865 (1,425,784) 793,664 (169,530) 341,236 10,958,996 599,454 (2,716,782) 8,769,555 3,997,646 (6,305,806) (11,905,053) (427,075,566) 427,190,728 (14,098,051) 1,269,282 1,447,500 2,716,782 (2,611,714) 2,759,057 \$147,343

Notes to Financial Statements

June 30, 1998 and 1997

(1) Organization and Summary of Significant Accounting Policies

Organization

The Carnegie Institution of Washington (Carnegie) conducts advanced research and training in the sciences. It carries out its scientific work in five research centers located throughout the United States and at an observatory in Chile. The centers are the Departments of Embryology, Plant Biology, and Terrestrial Magnetism, the Geophysical Laboratory, and the Observatories (astronomy). Carnegie's external income is mainly from gifts and federal grants and contracts. In addition, income from investments represents approximately 75 percent of Carnegie's total revenues.

Basis of Accounting and Presentation

The financial statements are prepared on the accrual basis of accounting. Expenses are separately reported for major programs and administrative and general expenses. Revenues are classified according to the existence or absence of donor-imposed restrictions. Also, satisfaction of donor-imposed restrictions are reported as releases of restrictions in the statements of activities.

Investments and Cash Equivalents

Carnegie's debt and equity investments are reported at their fair values. Carnegie also reports investments in partnerships at fair value as determined and reported by the general partners. All changes in fair value are recognized in the statements of activities. Carnegie considers all highly liquid debt instruments purchased with remaining maturities of 90 days or less to be cash equivalents. Money market and other highly liquid instruments held by investment managers are reported as investments.

Income Taxes

Carnegie is exempt from federal income tax under Section 501(c)(3) of the Internal Revenue Code (the Code). Accordingly, no provision for income

taxes is reflected in the accompanying financial statements. Carnegie is also an educational institution within the meaning of Section 170(b)(1)(A)(ii) of the Code. The Internal Revenue Service has classified Carnegie as other than a private foundation, as defined in Section 509(a) of the Code.

Fair Value of Financial Instruments

Financial instruments of Carnegie include cash equivalents, receivable, investments, bond proceeds held by trustee, accounts and broker payables, and bonds payable. The fair value of investments in debt and equity securities is based on quoted market prices. The fair value of investments in limited partnerships is based on information provided by the general partners.

The fair value of Series A bonds payable is based on quoted market prices. The fair value of Series B bonds payable is estimated to be the carrying value, since these bonds bear adjustable market rates.

The fair values of cash equivalents, receivable, and accounts and broker payable approximate their carrying values based on their short maturities.

Use of Estimates

The preparation of financial statements in conformity with generally accepted accounting principles requires management to make estimates and assumptions that affect the reported amounts of assets and liabilities and disclosure of contingent assets and liabilities at the date of the financial statements. They also affect the reported amounts of revenues and expenses during the reporting period. Actual results could differ from those estimates.

Property and Equipment

Carnegie capitalizes expenditures for land, buildings and leasehold improvements, telescopes, scientific and administrative equipment, and projects in progress. Routine replacement, maintenance, and repairs are charged to expense.

Depreciation is computed on a straight-line basis over the following estimated useful lives:

Buildings and telescopes

50 years

Leasehold improvements

lesser of 25 years or the remaining term of the

lease

Scientific and

administrative equipment

5 years

Contributions

Contributions are classified based on the existence of donor-imposed restrictions. Contributions and net assets are classified as follows:

Unrestricted – includes all contributions received without donor-imposed restrictions on use or time.

Temporarily restricted – includes contributions with donor-imposed restrictions as to purpose of gift or time period expended.

Permanently restricted – generally includes endowment gifts in which donors stipulated that the corpus be invested in perpetuity. Only the investment income generated from endowments may be spent. Certain endowments require that a portion of the investment income be reinvested in perpetuity.

Gifts of long-lived assets, such as buildings or equipment, are considered unrestricted when placed in service. Cash gifts restricted for investment in long-lived assets are released from restriction when the asset is acquired or as costs are incurred for constructed assets.

Grants

Carnegie records revenues on grants from federal agencies only to the extent that reimbursable expenses are incurred. Accordingly, funds received in excess of reimbursable expenses are recorded as deferred revenue, and expenses in excess of reimbursements are recorded as accounts receivable. Reimbursement of indirect costs is based upon provisional rates which are subject to subsequent audit by Carnegie's federal cognizant agency, the National Science Foundation.

Reclassifications

Certain prior year amounts were reclassified to conform to the current year presentation.

(2) Contributions Receivable

Contributions receivable are summarized as follows at June 30, 1998:

Unconditional promises expected to be collected in years ended June 30

1999	\$ 2,041,690
2000	144,690
2001	102,000
2002	27,000
2003	27,000
2004 and later	71,891

\$ 2,414,271

(3) Investments

At June 30, 1998 and 1997, investments at fair value consisted of the following:

	1998	. 1997
Time deposits and money	/	
market funds	\$ 20,253,740	18,488,606
Debt mutal funds	55,886,196	65,150,721
Debt securities	40,071,660	24,122,834
Real Estate Partnerships	51,744,690	39,657,484
Equity Securities	155,190,157	144,759,793
Limited partnerships	108,656,297	88,568,270
•	\$ 431,802,740	380,747,708

Investment income for the years ended June 30, 1998 and 1997, consisted of the following:

	1998	1997
Interest and dividends \$	13,092,269	11,744,238
Net realized gains	28,100,705	26,527,556
Net unrealized gains	19,490,807	19,213,223
Less - investment		
management expenses	(1,559,756)	(970,055)
		4 A
\$	59,124,025	56,514,962

Carnegie purchased and sold certain investment securities on dates prior to June 30, 1998. These trades were settled subsequent to June 30, 1998, and are reflected in the investment balances reported at year end. The net obligation for these unsettled trades is reported as broker payable in the accompanying statements of financial position.

The fair value for approximately \$33 million of Carnegie's \$160 million of real estate and limited partnership investments has been estimated by the general partners in the absence of readily ascertainable market values. However, the estimated fair values may differ from the values that would have been used had a ready market existed.

(4) Property and Equipment

At June 30, 1998 and 1997, property and equipment placed in service consisted of the following:

	1998	1997
Buildings and		
improvements \$	38,904,093	34,660,342
Scientific equipment	15,917,470	14,736,201
Telescopes	7,910,825	7,910,825
Administrative equipment	2,334,975	2,316,444
Land	787,896	787,896
Art	34,067	34,067
Less accumulated	65,889,326	60,445,775
depreciation	24,281,915	22,565,661
	\$41,607,411	37,880,114

At June 30, 1998 and 1997, construction in progress consisted of the following:

	1998	1997
Telescope Buildings Scientific equipment	\$ 38,447,209 1,147,369 1,047,919	26,924,587 1,523,337 289,520
	\$40,642,497	28,737,444

At June 30, 1998 and 1997, approximately \$44 million and \$34 million, respectively, of construction in progress and other property, net of accumulated depreciation, was located in Las Campanas, Chile. During 1998 and 1997, Carnegie capitalized net interest costs of approximately \$1,169,000 and \$1,154,000, respectively, as construction in progress.

(5) Magellan Consortium

During the year ended June 30, 1998, Carnegie entered into an agreement (Magellan Agreement) with four universities establishing a consortium to build and operate the Magellan telescopes. The two Magellan telescopes are currently under construction on Manqui Peak, Las Campanas in Chile. The total construction costs of the two telescopes are expected to be approximately \$72 million and will be recorded as assets by Carnegie. Title to the Magellan facilities is held by Carnegie. As of June 30, 1998, construction in progress of \$37,892,570 related to the Magellan project.

The university members of the consortium, by contribution to the construction and operating costs of Magellan, acquire rights of access and oversight as described in the Magellan Agreement. Total contributions by the university members for construction are expected to be \$36 million, 50% of the total expected costs and these monies are being used by Carnegie to finance part of the Magellan Telescopes' construction costs. As of June 30, 1998, the university members had contributed \$12,146,100 which is included in deferred revenue in the accompanying statement of financial position. The deferred revenue will be recognized ratably as income over the estimated useful lives of the telescopes.

(6) Bonds Payable

On November 1, 1993, Carnegie issued \$17.5 million each of secured Series A and Series B California Educational Facilities Authority Revenue tax-exempt bonds. Bond proceeds are used to finance the Magellan telescope project and the renovation of the facilities of the Observatories at Pasadena. The balances outstanding at June 30,

1998 and 1997, on the Series A issue totaled \$17,380,068 and \$17,357,224, respectively, and on the Series B issue totaled \$17,426,392 and \$17,412,372, respectively. The balances outstanding are net of unamortized bond issue costs and bond discount. Bond proceeds held by the trustee and unexpended at June 30, 1998 and 1997, totaled \$7,162,230 and \$11,159,876, respectively.

Series A bonds bear interest at 5.6 percent payable in arrears semiannually on each April 1 and October 1 and upon maturity on October 1, 2023. Series B bonds bear interest at variable money market rates in effect from time to time, up to a maximum of 12 percent over the applicable money market rate period of between one and 270 days and have a stated maturity of October 1, 2023. At the end of each money market rate period, Series B bondholders are required to offer the bonds for repurchase at the applicable money market rate. If repurchased, the Series B bonds would be resold at the current applicable money market rate and for a new rate period.

Carnegie is not required to repay the Series A and B bonds until the October 1, 2023, maturity date, and Carnegie has the intent and the ability to effect the purchase and resale of the Series B bonds through a tender agent; therefore all bonds payable are classified as long term. Sinking fund redemptions begin in 2019 in installments for both series. The fair value of Series A bonds payable at June 30, 1998 and 1997, based on quoted market prices is estimated at \$18,600,000 and \$18,300,000, respectively. The fair value of Series B bonds payable at June 30, 1998 and 1997, is estimated to approximate carrying value as the mandatory tender dates on which the bonds are repriced are generally within three months of year end.

(7) Employee Benefit Plans

Retirement Plan

Carnegie has a noncontributory, defined contribution, money-purchase retirement plan in which all United States personnel are eligible to participate. After one year's participation, an individual's benefits are fully vested. The Plan has been funded through individually owned annuities issued by Teachers' Insurance and Annuity Association (TIAA) and College Retirement Equities Fund (CREF). There are no unfunded past service costs. Total contributions made by Carnegie totaled approximately \$1,850,990 and \$1,783,000 for the years ended June 30, 1998 and 1997, respectively.

Postretirement Benefits Plan

Carnegie provides postretirement medical benefits to all employees who retire after age 55 and have at least ten years of service. Cash payments made by Carnegie for these benefits totaled approximately \$341,000 and \$374,000 for the years ended June 30, 1998 and 1997, respectively.

The expense for postretirement benefits in 1998 and 1997 under the provisions of SFAS No. 106 was approximately \$627,000 and \$950,000, respectively. The 1998 postretirement benefits expense was approximately \$286,000 more than the cash expense of \$341,000, and the 1997 postretirement benefits expense was approximately \$576,000 more than the cash expense of \$374,000. The postretirement benefits expense was allocated among program and supporting services expenses in the statements of activities.

The following items are the components of the net postretirement benefit cost for the years ended June 30, 1998 and 1997:

	1998	1997
Service cost - benefits earned during the year	\$ 237,000	314,000
Interest cost on projected	•	
benefit obligation Amortization of gain	502,000 (112,000)	636,000
- The decident of gain	(112,000)	
Accrued postretirement benefit cost	\$627,000	950,000

The following table sets forth the funded status of the postretirement medical benefits plan as of June 30, 1998 and 1997:

	1998	1997
Actuarial present value of the accumulated postretirement benefit obligation for:		
J	4,180,000	4,618,000
participants Other active	1,651,000	2,012,000
participants 	2,210,000	2,647,000
Accumulated postretirement benefit obligation for		
services rendered to date	8,041,000	9,277,000
Unrecognized net gain (loss)	1,795,000	(40,000)
Accrued postretirement benefit cost	\$9.836.000	9 237 000
Denetit Cost	\$9,836,000	9,237,000

The decrease in accrued postretirement benefit cost and the increase in the unrecognized net gain are a result of changes in the number of employees covered by the Plan.

The present value of the benefit obligation as of June 30, 1998, was determined using an assumed health care cost trend rate of 9.4 percent and an assumed discount rate of 6.75 percent. The present value of the benefit obligation as of June 30, 1997 was determined using an assumed health care cost trend rate of 10 percent and an assumed discount rate of 7.5 percent. Carnegie's policy is to fund postretirement benefits as claims and administrative fees are paid.

For measurement purposes, a 9.4 percent annual rate of increase in the per capita cost of covered health care benefits was assumed for 1998; the rate was assumed to decrease gradually to 5.5 percent in 13 years and remain at that level thereafter. The health care cost trend rate assumption has a signifi-

cant effect on the amounts reported. An increase of 1.0 percent in the health care cost trend rate used would have resulted in a \$1,209,000 increase in the present value of the accumulated benefit obligation at June 30, 1998, and a \$133,000 increase in the aggregate of service and interest cost components of net periodic postretirement benefit cost for the year ended June 30, 1998.

(8) Net Assets

At June 30, 1998 and 1997, temporarily restricted net assets were available to support the following donor-restricted purposes:

	1998	1997
Specific research programs Equipment acquisition and construction	\$ 9,278,140 4,894,287	8,225,980 7,360,110
	\$14,172,427	15,586,090

At June 30, 1998 and 1997, permanently restricted net assets consisted of permanent endowments, the income from which is available to support the following donor-restricted purposes:

	1998	1997
Specific research		
programs	\$ 12,747,371	11,478,089
Equipment acquisition		
and construction	1,204,719	1,204,719
General support (Carnegie endowment)	\$22,000,000	22,000,000
	Ψ22,000,000	
	\$35,952,090	34,682,808

During 1998 and 1997, Carnegie met donor-imposed requirements on certain gifts and, therefore, released temporarily restricted net assets as follows:

	1998	1997
Specific research programs	\$3,979,778	2,364,853
Equipment acquisition and construction	5,344,976	982,043
	\$9,324,754	3,346,896

(9) Federal Grants and Contracts

Costs charged to the federal government under cost-reimbursement grants and contracts are subject to government audit. Therefore, all such costs are subject to adjustment. Management believes that adjustments, if any, would not have a significant effect on the financial statements.

(10) Commitments

In 1997, Carnegie entered into a contract with the University of Arizona for the construction of the primary mirror and support system for the second telescope in the Magellan project. The amount of the contract is approximately \$9,700,000 of which approximately \$7,000,000 had not been incurred at June 30, 1998. Carnegie had previously entered into an agreement with the University of Arizona for the primary mirror and support system for the first telescope and had outstanding commitments of approximately \$700,000 at June 30, 1998. Carnegie also has other contracts relating to the construction of Magellan with outstanding commitments totalling approximately \$6,000,000.

Carnegie has outstanding commitments to invest approximately \$3.8 million in limited partnerships.

(II) Lease Arrangements

Carnegie leases a portion of the land it owns in Las Campanas, Chile to other organizations. These organizations have built and operate telescopes on the land. Most of the lease arrangements are not specific and some are at no-cost to the other organizations. One of the lease arrangements is noncancelable and has annual future rents of \$120,000 through fiscal year 2001. For the no-cost leases, the value of the leases could not be determined and is not considered significant, and, accordingly, contributions have not been recorded in the financial statements.

Carnegie also leases a portion of one of its laboratories to another organization for an indefinite term. Rents to be received under the agreement are approximately \$183,000 annually, adjusted for CPI increases.

Carnegie leases land and buildings. The monetary terms of the leases are considerably below fair value, however, these terms were developed considering other non-monetary transactions between Carnegie and the lessors. The substance of the transactions indicates arms-length terms between Carnegie and the lessors. The monetary value of the leases could not be determined, and has not been recorded in the financial statements.

Schedules of Expenses

Schedule 1

Years ended June 30, 1998 and 1997

1998

1997

	Carnegie funds	Federal and private grants	Total expenses	Carnegie funds	Federal and private grants	Total expenses	
Personnel costs:							
Salaries	\$10,341,061	2,852,217	13,193,278	9,763,705	2,972,498	12,736,203	
Fringe benefits and payroll taxes	3,512,361	773,285	4,285,646	3,616,358	800,952	4,417,310	
Total personnel costs	13,853,422	3,625,502	17,478,924	13,380,063	3,773,450	17,153,513	
Fellowship grants and awards	1,325,949	888,367	2,214,316	1,360,445	647,853	2,008,298	
Depreciation	2,474,898	0	2,474,898	2,458,035	0	2,458,035	
General expenses:							
Educational and research supplies	866,150	1,000,382	1,866,532	798,925	1,060,501	1,859,426	
Building maintenance and operation	1,512,049	33,229	1,545,278	1,744,184	387,676	2,131,860	
Travel and meetings	634,442	530,816	1,165,258	560,818	509,570	1,070,388	
Publications	38,197	84,898	123,095	32,348	79,656	112,004	
Shop	57,282	0	57,282	46,262	0	46,262	
Telephone	175,120	12,613	187,733	176,209	385	176,594	
Books and subscriptions	226,358	9,328	235,686	231,418	6,278	237,696	
Administrative and general	647,577	161,494	809,071	515,693	51,277	566,970	
Printing and copying	91,256	2,546	93,802	216,664	5,239	221,903	
Shipping and postage	110,560	65,522	176,082	108,851	39,494	148,345	
Insurance, taxes and professional fees	663,824	138,847	802,671	919,764	116,960	1,036,724	
Equipment	0	1,914,681	1,914,681	13,673	816,397	830,070	
Fund-raising expense	321,420	0	321,420	338,380	0	338,380	
Total general expenses	5,344,235	3,954,356	9,298,591	5,703,189	3,073,433	8,776,622	
Indirect costs – grants	(2,791,705)	2,791,705	0	(2,846,024)	2,846,024	0	
Capitalized scientific equipment and construction projects funded by							
Federal and private grants	(68,858)	0	(68,858)	(614,967)	0	(614,967)	
	\$20,137,941	11,259,930	31,397,871	19,440,741	10,340,760	29,781,501	

Abbott, Jennifer, 45
Abelson, Philip H., 4, 5, 79
Accardi, AnnMarie, 82
Acton, Mark, 82
Adam, Luc, 34
Aldrich, Thomas, 70
Alexander, Conel, 12, 64, 70
Ali, Rehan, 82
Alvarado, Alejandro Sánchez, 8, 45
Ash, Richard, 63, 70, 82

Babcock, Horace, 55 Badro, James, 82 Baird, Euan, 5, 16 Ball, Timothy, 34 Becker, Harry, 64, 70 Bell, David, 82 Bell, Peter, 82 Bellini, Michel, 45 Berengaut, Alexander, 82 Bernstein, Rebecca, 48, 54, 55 Berry, Deborah, 45 Berry, Joseph, 9, 30, 34 Bertka, Constance, 13, 82 Bertoglio, Valarie, 45 Bhaya, Devaki, 34 Bigelow, Bruce, 54, 55 Björkman, Olle, 8, 34 Blay, Christopher, 70 Bloomfield, Emily, 82 Boise, James, 15 Bond, Tim, 54 Borjigin, Jimo, 17, 44 Boss, Alan, 10, 61, 70 Boyd, Joe, 79, 82 Brandes, Jay, 82 Briggs, Winslow, 8, 34 Broun, Pierre, 34 Brown, Louis, 70 Brown, Donald, 8, 43, 45 Burley, Greg, 55

Calvi, Brian, 45
Carlson, Richard, 70
Chick, Kenneth, 61, 70
Christie, John, 34
Cifuentes, Inés, 87
Cockell, Charles, 34
Cody, George, 77, 79, 82
Coffeen, Mary, 15
Cohen, Ronald, 82
Cohen-Fix, Oma, 45
Colello, Gregory, 34
Coleman, William T., Jr., 5
Conrad, Pamela, 82
Cooper, Benjamin, 82
Crawford, John F., 5
Cutler, Sean, 34

Dalcanton, Julianne, 48, 55 Dandekar, Abhaya, 34 Das, Biswajit, 45 David, Edward E., Jr., 4, 5 Davidson, Paula, 82 Davies, John, 34 Dawid, Igor, 41 de Cuevas, Maggie, 45 De, Subarnarekha, 82 DeFries, Ruth, 32, 34 DeHaan, Robert, 18 Dej, Kim, 45 DeSantis, Stacia, 82 Diebold, John, 5 Domínguez, Jaime, 70 Dressler, Alan, 50, 54, 55 Drummond-Barbosa, Daniela, 45 Dymecki, Susan, 45

Ebert, James D., 4, 5 Ehrhardt, David, 34 Elrad, Dafna, 34 Ernst, W. Gary, 5, 18

Faber, Steve, 45 Faber, Sandra M., 5 Fan, Chen-Ming, 17, 42, 45 Farquhar, James, 82 Fassett, Caleb, 18, 70 Faulkner, Sarah, 70, 82 Fei, Yingwei, 13, 65, 82 Ferguson, Bruce W., 5 Field, Chris, 9, 30, 31, 34 Filley, Timothy, 82 Finger, Larry, 13, 75, 82 Fire, Andrew, 43, 45 Fisher, Shannon, 45 Fogel, Marilyn, 18, 77, 79, 82 Frantz, John, 79, 82 Freed, Andrew, 66, 70 Freedman, Wendy, 55 Fricke, Henry, 82 Friedlingstein, Pierre, 34 Frost, Daniel, 82 Frydman, Horacio, 45 Fu, Wei, 31, 34 Funkhouser, Kristine, 45 Furlow, David, 45

Galaz, Gaspar, 55 Gall, Joseph, 12, 45 Gallart, Carrie, 55 Gao, Stephen, 69, 70 Garvey, Susanne, 5, 87 Gellert, Michael E., 5 Giavalisco, Mauro, 55 Gillmor, Stewart, 34 Goelet, Robert G., 5 Golden, William T., 5, 18 Goncharov, Alexandre, 82 Goodfriend, Glenn, 79, 82 Graham, John, 70 Gramsch, Stephen, 82 Granger, Claire, 34 Gray, Caprice, 70 Greenewalt, David, 5 Greider, Nicole, 45 Grossman, Arthur, 8, 34 Guacci, Vincent, 45 Gülseren, Oguz, 82 Gunawardane, Ru, 45

Hadidiacos, Chris, 75 Hadley, Stephen, 82 Halpern, Marnie, 41, 45 Han, In-Seob, 34 Hanan, Niall, 34

Handwerger, Korie, 45 Hare, Ed, 79, 82 Harfe, Brian, 45 Hashimoto, Yasuhiro, 55 Haskins, Caryl P., 4, 5 Hauri, Erik, 12, 65, 70 Hazen, Robert, 17, 75, 77, 82 Hearst, William R., III, 5 Heckert, Richard E., 5 Hemley, Russell, 75, 81, 82 Hewlett, William R., 5 Heydenburg, Norman, 15 Hibbert, Heather, 82 Hiesey, William, 15 Hirose, Kei, 82 Ho, Louis, 17, 18 Hoffman, Laura, 34 Hoffman, Neil, 34 Hogan, Mary Eileen, 16 Hooft, Emilie, 68, 70 Hoppe, Kathryn, 70 Hsieh, Jenny, 45 Hu, Jingzhu, 82 Huala, Eva, 34 Huang, Haochu, 43, 45 Humayun, Munir, 18 Huntress, Wesley T., Jr., 17

lizuka, Yoshiyuki, 82 Inamori, Kazuo, 5 Irvine, Neil, 79, 82 Ita, Joel, 82

James, David, 67 James, Charles, 87 Director's essay, 21-23 James, David, 70 Jiao, Wenjie, 69, 70, 82 Joe, Valerie, 82 Joel, Geeske, 34 Johnson, Catherine, 67, 70 Johnson, Sherman, 15 Johnson, Suzanne Nora, 5

Kadak, Jorg, 34 Keddie, James, 34 Kehoe, David, 34 Kelly, William, 45 Kelson, Daniel, 50, 63, 70 Keyes, Linda, 45 Kitchel, Stephanie, 82 Klein, Nora, 82 Knezek, Patricia, 55 Kobayashi, Michihiko, 34 Konzett, Jürgen, 82 Kortenkamp, Stephen, 62, 70 Koshland, Douglas, 44, 45 Kostas, Steve, 43, 45 Krzeminski, Wojciech, 16, 55 Kunkel, William, 55

Laloraya, Shika, 45 Lassiter, John, 64, 70 Laubach, Gerald D., 5 Lavoie, Brigitte, 45 Lawler, David, 82 Lee, Catherine, 45 Li, Jie, 65, 70, 82 PAGE IO2

Index of Names

Li, Wei, 82
Liang, Jennifer, 41, 45
Lilly, Mary, 45
Lim, Vincent, 82
Linde, Alan, 69, 70
Lithgow-Bertelloni, Carolina, 66, 70
Little, Charles, 15
Liu, Hong, 70
Liu, Kelly, 45
Lively, John J., 5, 87
Lizarraga, Sofia, 45
Lu, Ren, 82
Lubin, Lori, 55
Lukowitz, Wolfgang, 34
Lund, Chris, 34

Ma, Yanzhang, 82 Macko, Steve, 79 Macomber, John D., 5 Malmberg, Russell, 34 Mao, Ho-kwang, 75, 81, 82 Marsh-Armstrong, Nick, 43, 45 Martin, William McChesney, Jr., 15 Marzke, Ron, 55 Matunis, Erika, 17, 44 May, Noah, 42 McCarthy, Patrick, 11, 55 McGaugh, Stacy, 62, 70 McGovern, Patrick, 67, 70 McMurtry, Burton J., 5 McWilliam, Andrew, 55 Megee, Paul, 45 Meluh, Pamela, 45 Mendez, Liz, 45 Menzies, Andrew, 70 Merkel, Sébastien, 82 Meserve, Richard A., 5 Mical, Timothy, 45 Michaud, Jacques, 42, 45 Miller, Bryan, 63, 70 Minarik, William, 65, 70, 82 Montgomery, Mary, 43, 45 Mulchaey, John, 50, 55, 62 Murphy, David, 54, 55 Mysen, Bjørn, 79, 82

Newmark, Phil, 45 Nikoloff, Michelle, 34 Nittler, Larry, 63, 70 Niyogi, Krishna, 8 Noblin, Xavier, 82 Nowak, Scott, 45

Oemler, Augustus, Jr., 5, 11, 55 Director's essay, 47-54 Ogas, Joseph, 34 Olney, Margaret, 34 Osbom, Elburt, 15

Park, Young Mok, 34 Parmenter, Dana, 34 Parnish, Susan, 45 Pepling, Melissa, 45 Perkins, Richard S., 5 Persson, Eric, 54, 55 Phelps, Randy, 55 Pike, William, 82 Pilgrim, Marsha, 34
Pinel, Virginie, 82
Polet, Jascha, 70
Polsenberg, Johanna, 34
Praseuth, Richard, 82
Press, Frank, 5, 18
Prewitt, Charles, 5, 16, 18, 82
Director's essay, 75-81

Randerson, Jim, 32, 34 Regan, Michael, 62, 70 Remo, Ben, 43 Reymond, Philippe, 34 Rhee, Seung, 34 Ribas-Carbo, Miguel, 34 Richmond, Todd, 34 Rillig, Matthias, 34 Rochaix, Jean-David, 34 Rorth, Pernille, 45 Roth, Miguel, 55 Rubin, Vera, 17, 48, 62, 70 Rubinstein, Amy, 41, 45 Ruimy, Anne, 34 Rumble, Douglas, 64, 79, 82 Rümpker, Georg, 68, 70 Runkle, Matthew, 70 Rush, Brian, 55

Rutter, William J., 5 Sacks, Selwyn, 7, 70 Sághi-Szabó, Gotthard, 82 Sandage, Allan, 16, 52, 55 Scheible, Wolf-Ruediger, 34 Schiff, Céline, 34 Schindelbeck, Thomas, 82 Schuenemann, Danja, 34 Schwarz, Rakefet, 34 Schweizer, François, 10, 63, 70 Scott, Bryan, 82 Seamans, Robert C., Jr., 5 Searle, Leonard, 55 Seeman, Michael, 16 Shaw, Rebecca, 34 Shectman, Stephen, 54, 55 Shieh, Sean, 82 Shimogawara, Kosuke, 34 Shirey, Steven, 17, 70 Shu, Jinfu, 82 Sieber, Patrick, 34 Silver, Paul, 17, 66, 67, 68, 69, 70 Singer, Maxine, 5, 18, 87 President's commentary, 7-14 Publications of, 88 Skibbens, Robert, 45 Slesinger, Audrey, 82 Solomon, Sean, 5, 9, 17, 70 Director's essay, 59-69 Somayazulu, Madduri, 82 Somerville, Christopher, 5, 9, 17, 34 Director's essay, 25-33 Somerville, Shauna, 9, 27, 34

Spradling, Allan, 5, 45

Stanton, Frank, 5, 18

Stephens, Branson, 70

Stacey, Frank, 70

Still, Chris, 34

Director's essay, 37-44

Stixrude, Lars, 18 Stone, Christopher, 5 Storrie-Lómbardi, Lisa, 55 Struzhkin, Viktor, 82 Sutin, Brian, 54, 55 Swensen, David F., 5

Taylor, Milton, 15
Teece, Mark, 82
Tera, Fouad, 16, 70
Thayer, Susan, 34
Thompson, Ian, 55
Thordal-Christensen, Hans, 34
Timmons, Lisa, 45
Tomascak, Paul, 64, 70
Tom, Margaret, 34
Townes, Charles H., 5, 16, 18
Trager, Scott, 50, 55
Tu, Chao-Jung, 34
Turner, William I. M., Jr., 5

Urban, Thomas N., 5

van der Lee, Suzan, 67, 70, 82 van Waasbergen, Lori, 34 Vanhala, Harri, 60, 70 Vasquez, Susan, 87 Vaulot, Daniel, 34 Villand, Per, 34 Virgo, Dave, 79, 82 Vogel, John, 34 Vokroy, Joe, 16

Waldbauer, Jacob, 82 Wang, Zengfeng, 45 Waterman, Andrew, 18, 70 Weeks, Donald, 34 Wehmiller, John, 79 Weinberg, Sidney J., Jr., 5 Weinberger, Michelle, 82 Weiner, Ben, 49, 51, 55 Weinrib, David, 15 Wetherill, George, 10, 17, 62, 70 Weymann, Ray, 11, 52, 55 Wheeler, Kevin, 82 Whitmore, Brad, 63 Wiechert, Uwe, 82 Wiese, Christiane, 45 Wilde, Andrew, 45 Wilsbach, Kathleen, 45 Wilson, Iain, 34 Wu, Zheng-an, 45 Wykoff, Dennis, 34

Xie, Ting, 45 Xu, Sequin, 43

Yan, Lin, 55 Yang, Hexiong, 82 Yoder, Hatten S., Jr., 18, 77, 80, 82

Zabludoff, Ann, 50 Zavala, Karina, 70 Zha, Chang-Sheng, 82 Zhang, James, 34 Zimmerman, Sarah, 70

CARNEGIE INSTITUTION OF WASHINGTON

One of the most effective ways of supporting the work of the Carnegie Institution of Washington is to include the institution in your estate plans. By making a bequest, you can support the institution well into the future.

A bequest is both a tangible device of your dedication to the Carnegie Institution and a way to generate significant tax savings for your estate. Some bequests to the institution have been directed to fellowships, chairs, and departmental research projects; some have been additions to the endowment; other bequests have been unrestricted.

The following sample language can be used in making a bequest to the Carnegie Institution:

"I give, and bequeath the sum of \$_____ (or % of my residuary estate) to the Carnegie Institution of Washington, 1530 P Street, N.W., Washington, DC 20005-1910."

For additional information, please call Susanne Garvey, Director of External Affairs, at 202.939.1128, or write:

Susanne Garvey

Director, External Affairs

CARNEGIE INSTITUTION OF WASHINGTON

1530 P Street, N.W.

Washington, DC 20005-1910

CARNEGIE INSTITUTION OF WASHINGTON

1530 P Street, NW Washington, DC 20005 tel 202.387.6400
fax 202.387.8092

web site (http://www.ciwc